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ELECTRONIC MASTER MONITOR AND ADVISORY DISPLAY SYSTEM,
HUMAN ENGINEERING SUMMARY REPORT.

GENERAL ELECTRIC COMPANY
AIRCRAFT EQUIPMENT DIVSION
BINGHAMTON, NY 13902

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The development of non-mission-related status information is one area of rotary wing instrumentation which has not kept pace with the state-of-art. This includes raw data, discrete and summary status information related to the engine, transmission, rotor, fuel, hydraulic and electrical subsystems. General Electric Co., under contract to the US Army, is presently developing an Electronic Master Monitor and Advisory Display System (EMMADS), which will integrate and display this "secondary" information on a single solid-state

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electroluminescent panel. Human Engineering effort in support of this development has assessed the information requirements, developed and tested information handling formats, and determined the necessary display/control design criteria.

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## ACKNOWLEDGEMENTS

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In addition to Ron Kurowsky, the Project Engineer from Ft. Monmouth, Murray Foster (HEL) and Joe Dickinson (ATL) comprised the EMMADS review panel which provided valuable critiques and recommendations throughout the program.

## ABSTRACT

This summary report describes the methodology, results and recommendations of the Human Factors Engineering (HFE) Program as part of the feasibility demonstration of an Electronic Master Monitor and Advisory Display System (EMMADS) for rotary-wing Army aircraft. Program accomplishments documented herein include:

a) A literature review to assess the influence of mission requirements and the nature of crew workload.

b) An information requirements analysis which identifies and categorizes the informational needs of the flight crew.

c) Critiques by experienced Army flight crews of preliminary system operating concepts and display information content.

d) Basic HFE testing to compare and validate formatting techniques for the presentation of analog/digital data.

e) The design of information-handling display formats and functionally-compatible control configurations.

f) Generation of HFE control/display design criteria which combined with the control/display formats provide a definition of necessary hardware capabilities.

g) Generation of an operational scenario (using 35 mm slides taken from an AC gas plasma display) which simulates EMMADS formats for APU and engine start checklist sequences and basic, worst case and faulted subsystem displays.

h) Recommendations for further HFE testing

Evaluations of the operational and informational requirements (activities a through c) for an EMMADS was based on representative aircraft from the following helicopter groups: Utility (UH-60A); Cargo (CH-47C); Observation (OH-58C); and Attack (YAH-64). The included control/display formats and corresponding hardware requirements are designed for the CH-47C.

## SECTION I - INTRODUCTION

The operational environment of today's helicopter flight crews is complicated by two factors- the natural hazards of vegetation and terrain created by Nap of the Earth (NOE) and other low level mission profiles, and the demands of increasingly complex helicopter subsystems and related instrumentation. Consequently the visual, mental and manual workloads of pilot and copilot are elevated, often beyond the limits of reliable performance. The combination of these environmental hazards and hardware complexities often results in an increased accident rate and/or a reduction of mission effectiveness.

Towards a solution to this growing problem it is the overall intent of the proposed Electronic Master Monitor and Advisory Display System (EMMADS) to significantly reduce crew workload. This will be accomplished by the application of state-of-the-art control and display technologies configured to provide the crew with the maximum amount of relevant information while requiring minimal operator attention or interaction.

In support of the design and evaluation of the EMMADS solid-state, programmable, feasibility model it is the specific responsibility of the Human Factors Engineering (HFE) Program to:

- Analyze the tactical, environmental, and hardware factors which contribute to the adverse crew workloads
- Define a conceptual approach which satisfies the man-machine-information requirements for the given flight operations and environmental conditions.

- Specify operational philosophy and control and display design criteria necessary for hardware implementation and feasibility model demonstration.
- Recommend control and display formats which provide effective information transfer to the crew with minimal operator interaction.
- Test and evaluate both conceptual and hardware recommendations to validate the feasibility and efficiency of the total man-machine interface.

A schematic overview of the HFE Program is included as Figure 1A.

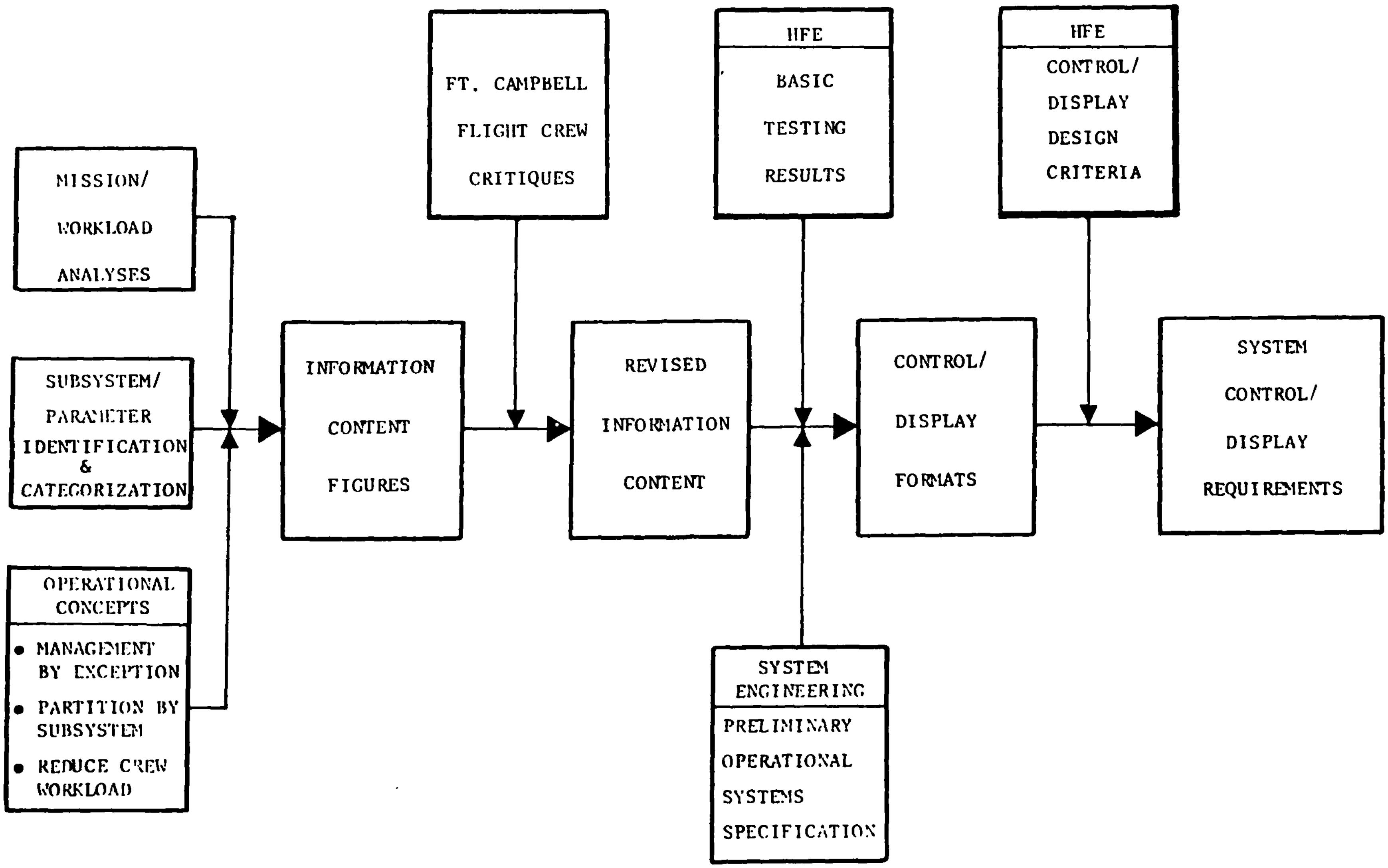



FIGURE 1A
SCHEMATIC SUMMARY OF EMMADS HFE PROGRAM

## SECTION II - MISSION/WORKLOAD ANALYSIS

The purpose of this program phase is to identify those aspects of the physical environment, mission requirements, and operational crew activity which impact the conceptual and hardware design of an EMMADS. Four classes of Army helicopters were selected for investigation and potential EMMADS implementation. These classes and the specified representative aircraft are:

- Cargo - CH-47C
- Utility - UH-60A
- Scout - OH-58C
- Attack - YAH-64

To qualitatively assess workload problems in terms of mission requirements and rotary wing flight operation, a literature review was conducted. Helicopter related research in the following areas was evaluated:

- Operator Workload Assessment
- Mission Profile Analysis
- Information Transfer
- Design of Optimal Cockpit Configurations
- General Man-Machine Interface Analyses

In addition to these specific studies, standard field manuals, helicopter operator's manuals, crew checklists, etc. were reviewed to provide familiarization with the specific operational hardware/procedures for the CH-47C, UH-60A, OH-58C, and YAH-64. A bibliography is provided in Appendix A.

SUMMARY

The concensus of the workload- related studies suggest that the visual and mental workloads of helicopter flight crews are most extreme during NOE, low-level and night operations. This condition (of extreme workload) is brought about by the need to maintain almost constant visual attention outside the aircraft to avoid and maneuver through vegetation and other terrain hazards. Generally it is the pilot who, in addition to maintaining control of the aircraft, directs nearly all of his visual attention outside the cockpit. In a similar fashion, the copilot is involved with visual tasks outside the aircraft as well as operational duties within the cockpit as he provides navigational assistance to the pilot while tuning radios, monitoring instruments, etc. These duties of the crew, during NOE and similar operations, consittute such a demand on attention that certain routine duties such as instrument monitoring often receive little or no attention.

Studies related to quantitative assessment of visual workload (using objective measures of pilot eye movement and subjective pilot survey techniques) indicate that during NOE flights, visual attention devoted to monitoring engine, drivetrain, and related instruments may constitute from zero to 7% of the crew's total visual activity. With so little attention paid to critical engine and drive train instruments it is entirely possible than an impending problem could go unnoticed and, within a matter of seconds, could become an emergency situation. For example, with high gross weight aircraft operating in NOE conditions, the resulting high crew workload conditions could easily let go undetected power related problems e.g., overtorques, which are likely to occur during Dash, Bound or Unmasking maneuvers.

The possibility of undetected pending or immediate problems is even more likely for an attack aircraft flying NOE during a target acquisition/engagement mission. Whether the target acquisition is manual or by means of sophisticated tracking equipment, the duties add to the already heavy visual workload of the copilot/gunner. Since the copilot/gunner is usually responsible for instrument monitoring, the task is met with even less visual attention, resulting in a higher probability of undetected problems.

From the overview of crew workload provided by the literature and the specific goal of EMMADS which is to reduce this workload, a design philosophy for this integrated display system will be defined. Throughout all phases of conceptual design and hardware implementation, reduction of the high workload imposed by NOE or other conditions will be a driving function for all trade-offs related to the optimization of the man-machine interface. Although system design will be driven by the need to reduce crew workload, implementation of this philosophy will not prevent manual crew interrogation of system status at any time. Automatic monitoring of subsystem status will be performed by the system as an aid to the crew while they are otherwise occupied. Although subsystem monitoring is continuously performed by the system, the display of this information either automatically (by exception) or by operator interrogation is always at the discretion of the crew.

## SECTION III - INFORMATION REQUIREMENTS ANALYSIS

### GENERAL

It is the purpose of this phase of the HFE Program to identify non-flight subsystem information required by the flight crew for routine and emergency flight operations. These non-flight subsystems include the engine, transmission, fuel, hydraulic and electrical plus a miscellaneous category to include environment controls (light, heat ventilation) landing gear, cargo hook and other accessories.

The description of this necessary data includes a time-related (mission/flight phase) component if there are unique requirements with respect to the type of mission or a particular phase of flight, e.g. take-off, cruise, landing, etc. In addition to the time-related characteristic of the subsystem information, the most appropriate form of display presentation (analog, digital, discrete, etc.) is also determined based on crew requirements.

A categorical description of the information requirements as described above provides the starting point for the conceptual design of an EMMADS. From this information description, candidate control/display configurations and operational concepts can be generated and subjected to evaluation by Systems Engineering and by available flight crews. At this point, preliminary assessments of control and display hardware/software requirements can be made.

### SUBSYSTEM/PARAMETER IDENTIFICATION

It was the intent of this effort to tabulate and categorize, by subsystem, every indication presently available to the crew regarding the status of the (previously indicated)non-flight subsystems. This was accomplished by

joint participation of Systems Engineering and HFE and was concurrent with the conduct of the Task 1- Signal Analysis. Similarities are apparent in the results of each effort in that the basic tabulation of parameters and indications by subsystem are identical. The Task 1 Signal Analysis quantized each indication according to electrical signal, sensor type, display type, operating ranges, etc. The HFE evaluation sought to categorize the same data in a specific operational sense according to "when" the indications are necessary and in what form are they most expediently displayed for the crew to make best use of their content.

For the purposes of this categorization the "when" was characterized by the following choices:

- Continuously - Throughout all flight modes
- Only During a Specific Flight Phase
- By Exception - Only when normal operating limits are exceeded, failure has occurred, or when status is inappropritate for existing flight conditions
- Upon manual request by the crew

The "form" of presentation determined to be most expedient for crew assimilation was categorized as:

- Digital - Raw numeric values
- Analog - Spacial, scaler representation e.g. bar graphs, circular dials, positional scale and pointers, etc.

- Both Analog and Digital
- Discrete - Word(s) or symbol indicating status or position
- Discrete plus some recommended operating procedures corresponding to the condition
- Other

Using the form shown in Figure 1, a tabulation/categorization was performed by HFE and Systems Engineering and by available Ex-Army Pilot(s) employed by General Electric. A summary of the categorizations from each of the above participants for each of the four candidate aircraft is included as Appendix B.

The results of this Subsystem/Parameter Identification and Categorization were compared with similar evaluations found in Task 1 of the Sikorsky Subsystem Status Monitor Report. For the aircraft which were common to both programs (UH-60A, CH-47C and OH-58C) no significant differences were apparent.

A generalized summary of the results of these categorizations is shown in Table 1. The specific results of this information analysis (Appendix B) were used as the basis for a preliminary EMMADS design along with certain assumptions regarding system operation. Under the assumption that EMMADS should assist the pilot/copilot in being a manager of information rather than a manipulator of raw data, the philosophy of "management by exception" appeared a logical choice. This would suggest that the user be presented with only a select amount of information i.e., only that which the system has analyzed and found to be out of limits or in some way worthy of operator attention. This filtering of data would obviously reduce the amount of information presented and ideally would present only that information which was pertinent for the existing circumstances.

HELICOPTER: CH-47C

| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY 1 TO___ | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| ENG (1&2) | TORQUE | | X | | | | | | | X | | | |
| | N1 | | | ALL | | X | X | | | X | | | |
| | N1 CONT | | | | | X | | | | | | X | |
| | OIL TEMP | | | | | X | X | | | X | | | |
| | OIL TEMP - HIGH | | | | | X | | | | | | X | |
| | OIL PRES. | | | | | X | X | | | X | | | |
| | OIL PRES. - LOW | | | | | X | | | | | | X | |
| | OIL QTY - LOW | | | | | X | | | | | | X | |
| | PTIT | | | | | X | X | | | X | | | |
| | CHIP | | | | | X | | | | | | X | |
| | FIRE | | | | | X | | | | | | X | |
| | ENG OUT | | | | | X | | | | | | X | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| FUEL | QTY - TOTAL | | | ALL | | X | X | | X | | | | TANK SCHEMATIC |
| | QTY- (L & R, FWD | | | | | | X | | X | | | | TANK SCHEMATIC |
| | MAIN, AFT) | | | | | | | | | | | | |
| | PRESSURE (L, R) | | | | | X | X | | X | | | | TANK SCHEMATIC |
| | FUEL LOW (L, R) | | | | | X | | | | | X | | |
| | AUX PRES (L, R) | | | | | X | | | | | X | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

FIGURE 1

TABLE 1

GENERALIZED SUMMARY OF SUBSYSTEM/PARAMETER IDENTIFICATION

| PARAMETER/INDICATION | TO BE DISPLAYED |
|---|---|
| ROTOR RPM & ENGINE TORQUE | CONTINUOUSLY IN BOTH ANALOG & DIGITAL FORM |
| ENGINE OIL PRESSURES, TEMPERATURES, EXHAUST GAS TEMPERATURES, TURBINE SPEEDS | BY EXCEPTION AND UPON MANUAL REQUEST IN BOTH ANALOG AND DIGITAL FORM |
| FUEL QUANTITIES, HYDRAULIC PRESSURES, ELECTRICAL GENERATOR AND TRANS./RECTIFIER OUTPUTS & LOAD FACTORS, TRANSMISSION OIL TEMPERATURES AND PRESSURES | BY EXCEPTION AND UPON MANUAL REQUEST IN DIGITAL FORM |
| ALL OTHERS INCLUDING BOOST PUMP STATUS, CHIP DETECTION, SAS STATUS PLUS ALL INDICATIONS PRESENTLY ON THE CAUTION WARNING PANEL | BY EXCEPTION IN DISCRETE FORM (WORD OR SYMBOL) |

Such an approach is necessary to help unburden the crew from the routine chore of manually monitoring all subsystem data, checking status and being constantly aware of any aberrant value or atypical rate of change.

Management by exception is also a logical choice where the allocation of tasks between man and computer should result in a distribution where each has responsibilities commensurate with his/its own relative capabilities. With the availability of state-of-the-art computational equipment, today's computer is a unanimous choice to perform such routine status and parameter monitoring.

Given that information management by exception will be the responsibility of the EMMADS computer, two questions require consideration for logical system design- "How Much" and "What Kind" of information should be presented in the event of failures and/or abnormal parameter excursions?

The decision to partition displayed information by subsystem, for both the "by exception" and "manual interrogation" modes, was made for the following reasons:

1. The occurrence of a fault in a specific subsystem is relatively independent of the simultaneous occurrence of a fault in another subsystem. For example, the loss of oil pressure in an engine would not cause or be caused by an abnormality in transmission oil parameters. This argument is not intended to be universally valid. Because of the overall dependence of many of the subsystems, basic performance parameters e.g., rotor RPM and torque, are obviously related to catastrophic failures such as engine flame-outs or transmission failures.

Similarly the failure of the AGB quill shaft (CH-47) results in a loss of both the hydraulic and electrical systems, but these occurrences are more exception than rule.

2. The excursion (beyond normal limits) of certain parameters, e.g. engine oil pressure, is often followed by, caused by or associated with an excursion of another parameter in the same subsystem, namely engine oil temperature.

3. For certain failures (especially electrical and hydraulic), standard procedures require that the back up or parallel component (system 2) be activated or checked out upon the occurrence of a failure (in System 1) and vice versa.

Combining the information requirements compiled from the subsystem/parameter categorization, the management by exception philosophy and the decision to partition displayed information by subsystem, an EMMADS system concept was initialized. The preliminary design was characterized by the following features:

- Continuous Display of certain parameters (Rotor RPM and Torque)
- Simultaneous Display (by exception) of both a textual warning message (message capsule comprised of words/abbreviations) and the corresponding subsystem raw data. The raw data includes analog and digital parameter values and discrete status indications.
- Manually accessible and/or automatically displayed emergency procedures corresponding to a current fault condition.
- Manually accessible raw data for each subsystem, independent of the existence of failures.

- Checklists (interactive with helicopter subsystems or merely a queing device, representative of present-day hard copy checklists) for the conduct of routine start-up, hover, take-off, shut-down, etc. operational procedures.
- Programmable, multi-function pushbuttons for operator interaction with the system.

As defined by the functions and capabilities described in the above preliminary system features, a definition of EMMADS was set forth in the form of Information Content Figures. Shown in Appendix C, these figures pictorially describe, on a per subsystem basis, the proposed information content to be presented either by exception or as a result of manual request. A unique set of figures was compiled for each of the candidate helicopters.

Although not the intent of these figures, certain format attributes were incorporated at this point to provide some pictorial realism representative of an actual display. This form of system definition would provide a quasi-realistic representation of an EMMADS display including functional attributes and information content.

## SECTION IV - FLIGHT CREW CRITIQUES

A validation of the proposed EMMADS concept and implementation techniques was conducted at Ft. Campbell, Ky. with the assistance of experienced flight crews who, at the time, held current ratings for the CH-47C, OH-58C, UH-1, UH-60A and AH-1. A summary of the number of participants and their respective flight time in the above aircraft is shown in Figure 2.

At each of four critique sessions, pilots were briefed on the overall EMMADS Program and were then given a brief overview of the functional attributes/capabilities of the proposed EMMADS. An EMMADS system description document was also provided (Appendix D). Crews were then asked to complete survey sheets (Appendix C) per the instructions provided. It was emphasized that information content and system concept were the primary areas of interest in the survey, while specific format comments should not be considered.

As shown in the survey sheets (Appendix C) pilots were asked to provide other parameters/indications and/or additional warning capsules that they considered desirable in an EMMADS system. Per the survey instructions pilots were asked to consider such things as:

- Extreme environmental conditions (jungle, arctic, high elevation, night, etc.)
- Composite or synthetic indications (not presently available on conventional aircraft) such as fuel time remaining.
- Trend indications representing an abnormal rate of change of a parameter prior to exceeding a normal limit

PILOT CRITIQUES

FT. CAMPBELL, KY.

JAN. 14, 1980

| AIRCRAFT | NO. OF PILOTS | EXPERIENCE<br>AVERAGE SPECIFIC AIRCRAFT HOURS | AVERAGE TOTAL FLIGHT HOURS |
|---|---|---|---|
| CH-47 | 3 | 1600 | 3133 |
| OH-58 | 4 | 571 | 1249 |
| UH-60 | 6 | 82 | 624 |
| UH-1 | 17 | 746 | 1377 |
| AH-1 | 4 | 289 | 1320 |

FIGURE 2

Results of the flight crew critiques are summarized in Table 2. A suggestion provided by almost every participant was the inclusion of time and/or fuel remaining among the continuously displayed parameters. Trend and/or audio indications for increasing/decreasing engine and transmission oil temperatures, pressures, and quantities was a prevalent suggestion.

The Crew Survey Results were reviewed by HFE and Systems Engineering and in-house helicopter pilots. Consideration for possible inclusion in EMMADS was based on:

- Frequency of the suggestion across crews
- Relative potential for reducing workload
- The need for sophisticated sensors for implementation
- General compatibility with the proposed operational concept

Those suggestions scoring well with respect to the above criteria were included in a revised information content summary. These additions are listed in Table 3 for CH-47 application.

TABLE 2

SUMMARY OF FT. CAMPBELL FLIGHT CREW CRITIQUES

| | CH-47C | UH-60A | OH-58C | AH-1 |
|---|---|---|---|---|
| CONTINUOUS DISPLAY | FUEL REMAINING | FUEL TIME REMAINING | HIGH ROTOR RPM<br>(FUEL) TIME REMAINING<br>NEAR/OVER TORQUE-AUDIO | HIGH ROTOR RPM - AUDIO<br>(FUEL) TIME REMAINING |
| ENG. DISPLAY | N2 GOV. FAILURE APU WARNINGS, OIL (TEMP, PRESSURE, QTY) TRENDS | OIL TEMP - TREND<br>ENG FIRE - AUDIO | OIL PRESSURE-HI<br>SYMBOL CHANGE TO INDICATE DIRECTION OF TREND | OIL PRESSURE - HI<br>LO/HIGH SIDE GOV.-FAILURE<br>EMERGENCY FUEL CTRL<br>FIRE LOCATION INDICATION |
| TRANSMISSION | OIL FILTER BYPASS | OIL TEMP - TREND<br>OIL HOT - AUDIO<br>OIL PRESSURE - TREND AND AUDIO | OIL PRESSURE - HI | 42° GBX - CHIP<br>OIL PRESSURE - HI<br>OIL FILTER-BYPASS |
| FUEL | MAIN BOOST PUMP FAILURE, FLOW RATE | | CONSUMPTION RATE - HI<br>FLOW RATE | FUEL PUMP PRESSURE<br>BOOST PUMP PRESSURE |
| HYDRAULIC | OIL FILTER BYPASS<br>UTILITY COOLER FAN FAILURE | REVERVOIR QTY - TREND | PRESSURE - TREND<br>PITCH/ROLL/COLLECTIVE SERVOS-OUT | |
| ELECTRICAL | BUS TIE FAILURE<br>ELIMINATE THE EXT PWR INDICATION | GEN FAILURE - AUDIO | BATTERY/INVERTER VOLTS<br>BATTERY CHARGING CONDITION (BEFORE SHUTDOWN) | BATTERY VOLTS<br>RECTIFIER-VOLTS<br>AC-AMPS |

TABLE 3

ADDITIONAL CH-47 INDICATIONS RESULTING FROM
FT. CAMPBELL FLIGHT CREW CRITIQUES

| DISPLAY | ADDITION |
|---|---|
| CONTINUOUS | FUEL TIME REMAINING |
| ENGINE | N2 GOV. FAILURE, OIL TEMP, PRESSURE AND QUANTITY TRENDS |
| TRANSMISSION | OIL PRESSURE AND TEMPERATURE TRENDS |
| FUEL | MAIN BOOST PUMP FAILURE |
| HYDRAULIC | UTILITY COOLER FAN FAILURE |
| ELECTRICAL | BUS TIE FAILURE (AC & DC) |
| MISCELLANEOUS | ELIMINATE EXTERNAL POWER INDICATION |

## SECTION V - HFE TEST AND EVALUATION

One of the responsibilities of the HFE Program is to insure that information presented on the EMMADS is readily interpreted by the crew. This interpretability is contingent on several design considerations. In a macro sense the overall arrangement and density of information is critical. Too much or improperly formatted data may create an information display that is too busy for efficient user readability. At a finer level of detail it is also necessary that the elemental units (alphanumeric and/or symbolic), used to portray the information, be of sufficient size and clarity for rapid readability. The first of these considerations will be considered in this section, the second in Section VI.

With the advent of mass media displays (CRT, LED, LCD, EL, etc.), several alternatives become available in the presentation of data. Numeric value information, for example, might be displayed in analog or digital form. Generally the analog presentation is less precise (than digital) but it does afford certain characteristics/capabilities not available with and/or superior to the purely digital display. These include:

- At a glance reading (by spatial position) without the need to read characters
- Time rate of change via scalar movement
- A sense of proportion: What the present value is relative to the maximum value or to some desirable/undesirable intermediate point. The convenient notation of these intermediate values is also a unique feature.

Digital presentations have the advantages of

- High precision without interpolation
- Minimum display space requirements

Obvious advantages are available with each of these types of presentation, and the requirements for either (or both) are dictated by the specific use of the information by the pilot/copilot. The most appropriate form of presentation (based on operational crew requirements) for each of the presently displayed parameters was determined in Section II with the results shown in Appendix B. A similar categorization was performed for the additional parameters resulting from the Ft. Campbell flight crew critiques (Table 3).

Given that a most appropriate form (analog, digital or both) of parameter presentation has been determined, and that displayed information will be partitioned by subsystem, the arrangement of these data must be specified as the next step in the design of the EMMADS information handling system.

A review of the research literature regarding display formatting provides recommendations that are quite task specific with little or no methodological validation. Similarly, the HFE Design Guides, Mil Specs. and Handbooks provide little data and are, at best, incomplete.

Towards an answer to some of the generic questions of display formatting germane to EMMADS requirements, an HFE Basic Test program was undertaken. The intent was to compare and validate formatting techniques for analog/digital presentations while assessing their compatibility with electronic display media. The overall goal was to insure specific display readability and provide general information transfer effectiveness.

Format attributes evaluated in the Basic Testing (Figure 3) were the orientation of the analog scale and the configuration of the analog/digital combination.

Other characteristics and levels of the above categories were considered for evaluation. However, this level of detailed evaluation fell outside the scope of the existing program definition. Any design follow-on program should address this fine detail.

Figures 4 - 7 are black and white photographs of the slides used in the basic testing. The 8 vertical formats (Figures 4 & 5) are characterized by unique configurations of scale type (tape with pointer, bar graph), pointer type, and location of digital values (remote or adjacent to analog). Corresponding configurations of the horizontal formats are shown in Figures 6 & 7. All formats were similar with respect to the distribution of scale values. Each format, comprised of 4 pairs of tapes or bars (labeled A, B, C & D), was constructed such that in one of the four pairs the difference between the left and right value was about 20 units (Figure 4, Format B, Pair C). Also, one of the pairs had little or no difference between the left and right value (Fig. 4, Format B, Pair D). The remaining two pairs showed a difference between left and right values of about ten units.

## METHOD

Inasmuch as the ultimate application of these experimental results would be on an electronic display, it was deemed appropriate to use an (similar technology) electronic display as an experimental apparatus. This would help reduce the uncertainty and/or interaction of results with display media which might be present with the use of hard copy graphics or other non-electronic media.

## FORMAT ATTRIBUTES TO BE EVALUATED

- ORIENTATION OF ANALOG INDICATIONS
  HORIZONTAL VS. VERTICAL

- ANALOG/DIGITAL FORMAT TECHNIQUES

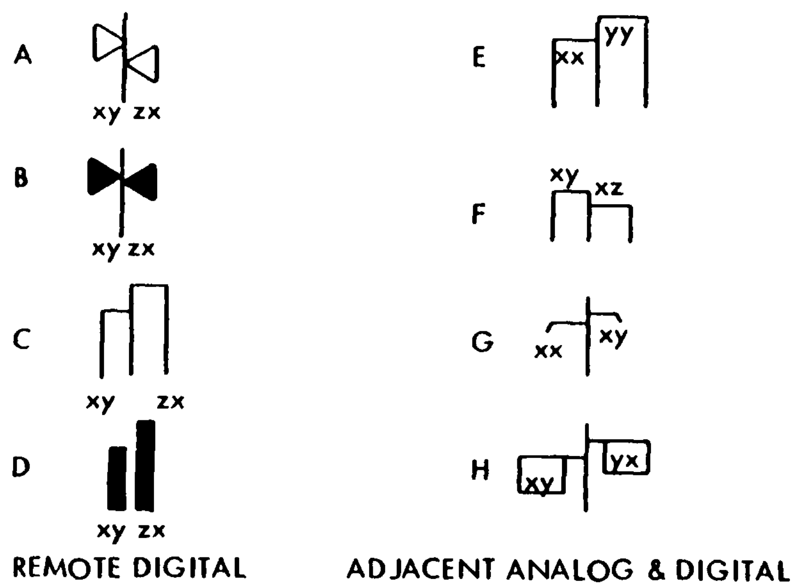



FIGURE 3

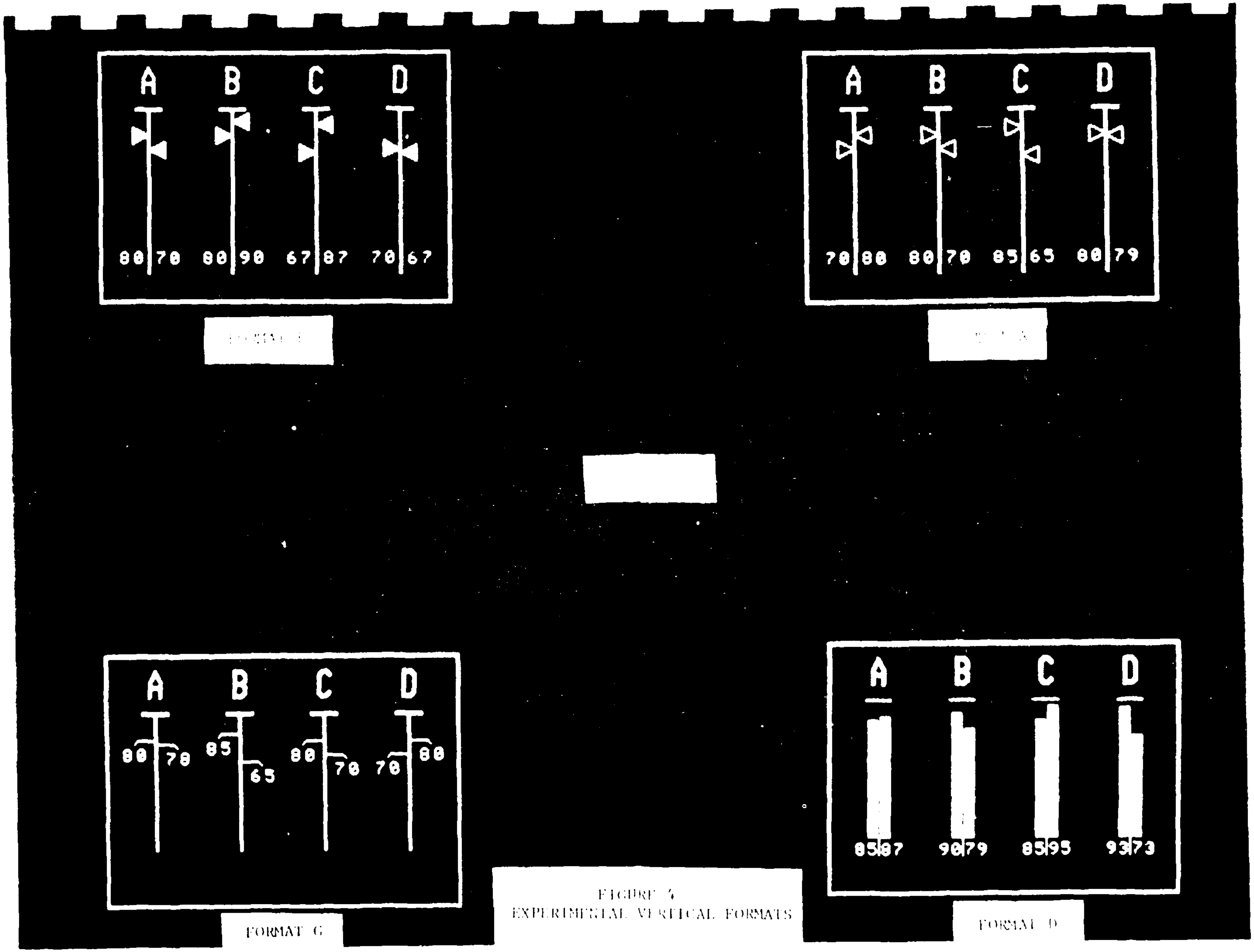
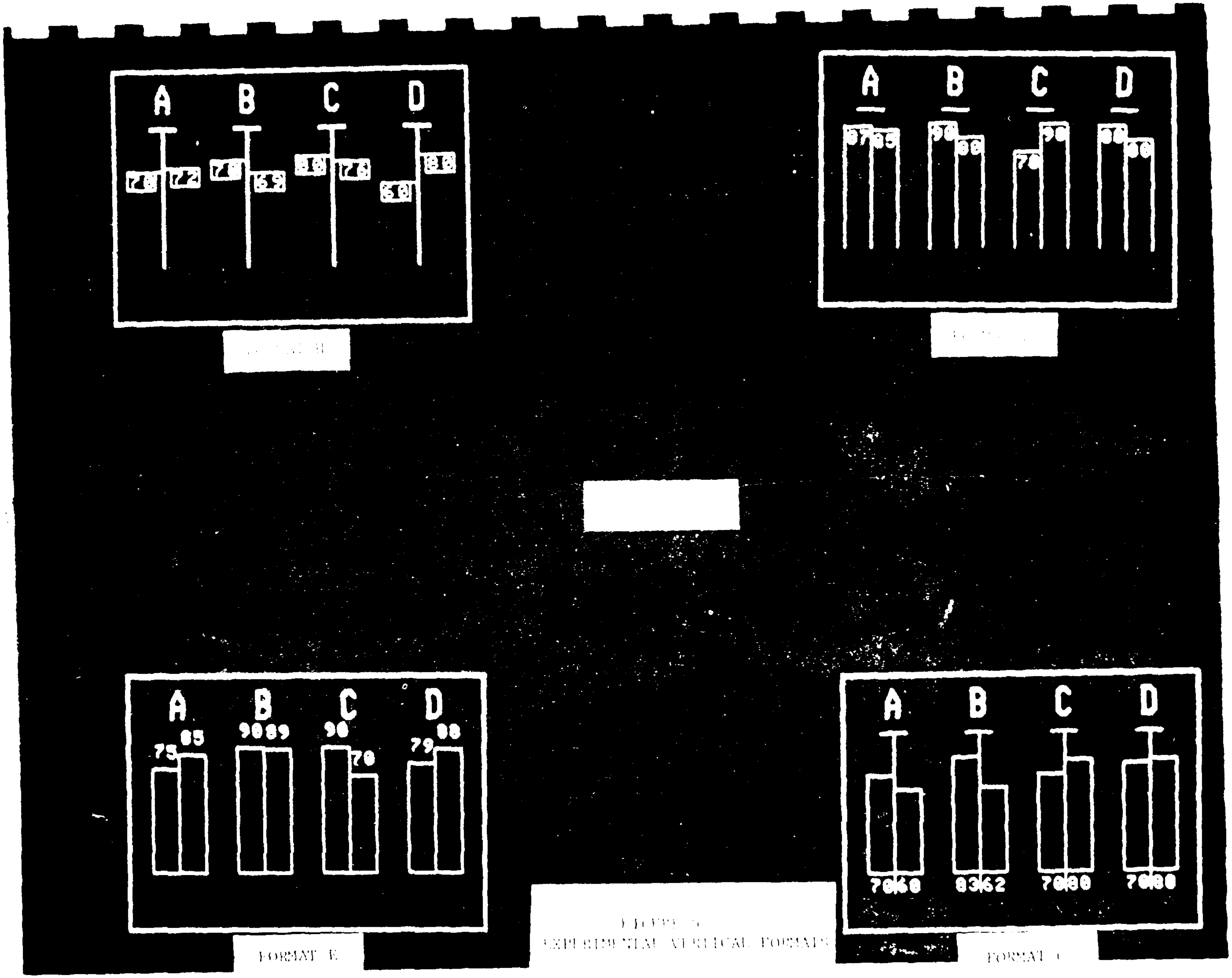



FIGURE 4
EXPERIMENTAL VERTICAL FORMATS




FORMAT E

EXPERIMENTAL VERTICAL FORMATS

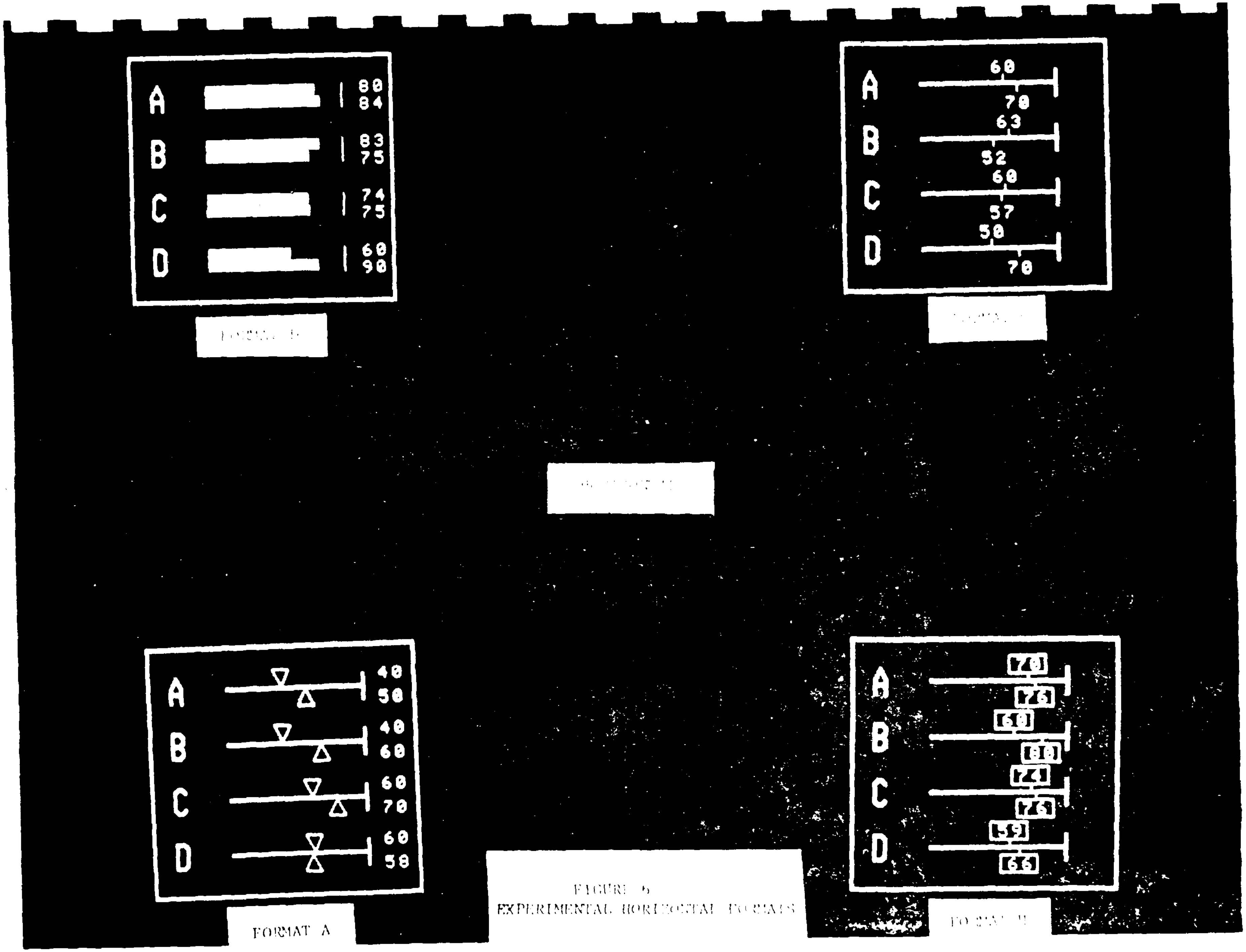
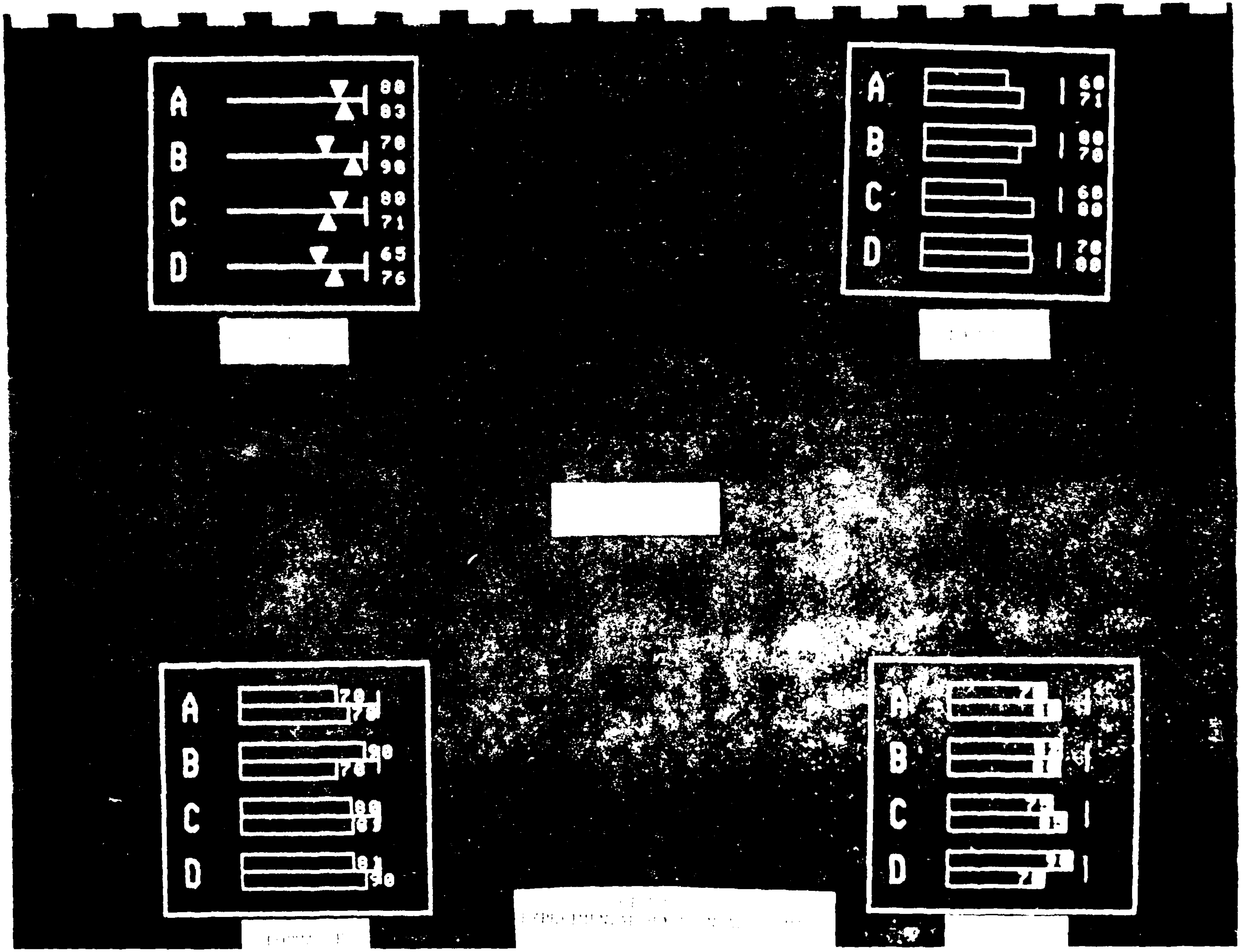



FIGURE 6
EXPERIMENTAL HORIZONTAL FORMATS



A
B
C
D
80
83
70
90
80
71
65
76
A
B
C
D
60
71
90
70
60
80
70
80
A
B
C
D
90
70
90
A
B
C
D

Because of its availability and similarity to the display chosen for the EMMADS feasibility demonstration model (Electroluminescent), and A-C gas plasma panel was used to generate source material for HFE testing.

The Owens-Illinois "Digi-Vue" is a flat panel gas plasma display with an active area of 8.5" x 8.5", 60 (round) cells per inch resolution, and a cell luminance of about 55 ft-L. The orange, plasma color is similar to that of the EL panel (with enhancement filter). The "Digi-Vue" display is part of a stand-alone, computer-aided learning console known as GETS (General Electric Training System) developed by G.E. Ordnance Systems for Naval Fleet Ballistic Missile Submarine Training. A photograph of the GETS console is shown in Figure 8.

Source material was generated on the GETS Display and 35 mm color slides were taken of each figure. A description of the rear-projected 35 mm slide display is shown in Figure 9. Subjects were seated with a viewing distance (to the rear projection screen) of about 28 in.

To provide repeatable, short exposure presentations of the display formats under evaluation, an electronically controlled shutter (tachistoscope) was used as shown in Figure 10. The short exposure technique was used for two reasons: To provide a well controlled level of reading difficulty and to simulate the operational flight situation of reading an instrument with minimal time available.

The exposure time used in this testing was 250 msec. This value was arrived at experimentally with a brief pilot study. It was found that exposure time on the order of 400 msec made the reading task too easy and correct answers were given on the first trial for every format under test.

Exposure values close to 100 msec increased the reading difficulty such that only one pair of values at a time could be comprehended. Consequently, the number of trials (exposures) required by subjects to determine the designated pair corresponded almost perfectly with the location of the specific pair on the format i.e. A= 1 trial, B= 2 trials, etc.

EXPERIMENTAL TASK

After reading instructions (Appendix E), being briefed on procedures, and being shown a sample format slide, subjects were informed that a max (min) difference situation was the object of the first half of testing. The test required that subjects identify which parameter pair (A, B, C or D) had the designated max (or min) difference between left and right values. A subject's score for each format was determined by the number of 250 msec exposures required to give a correct answer. Table 4 provides a detailed descrpiton of procedure, number of trials, etc. In addition to the max and min tasks, a third task was performed which required subjects to identify the absolute highest or lowest value on the display. Procedures were the same as for the max/min tasks.

At the end of the testing, participants were asked to indicate (from the instruction sheet) their first three format preferences (in order) with regard to overall ease of readability.

SUBJECTS

Participants in this testing were 29 male volunteers employed by GEOS in technical, engineering and administrative capacities. Ages ranged from 27 to 60 with a mean of 44. All participants attested to having 20-20 or better corrected vision. Test time, including reading of instructions, was about 45 minutes per subject.

## EXPERIMENTAL APPARATUS

### 1. DISPLAY

- REAR PROJECTED 35 MM SLIDE (TAKEN FROM DIGI-VUE, GAS-PLASMA PANEL)
- CONTENT: 4 VERTICAL OR 4 HORIZONTAL ANALOG-DIGITAL ARRAYS
- PROJECTED SIZE: 3.5" x 4.7"
- LUMINANCE: $\approx$ 55 FT-L
- RESOLUTION: 60 CELLS/INCH

### 2. PRESENTATION TECHNIQUE

- ELECTRONIC SHUTTER (TACHISTOSCOPE)
- EXPOSURE TIME: 250 MSEC

FIGURE 9

EXPERIMENTAL SET-UP

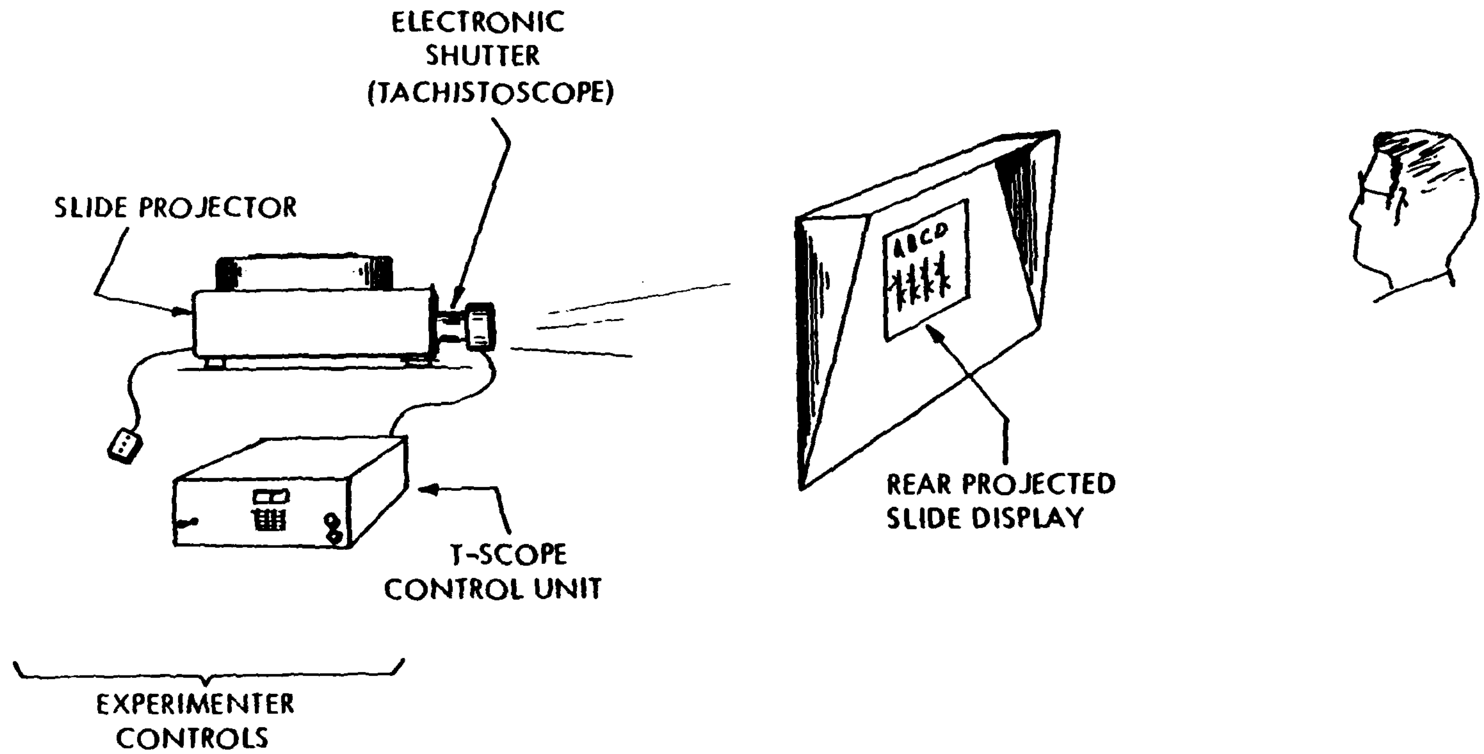



FIGURE 10

TABLE 4

## EXPERIMENTAL PROCEDURE

- SS READS SET OF INSTRUCTIONS
- EXPERIMENTER ANSERS QUESTIONS, EXPLAINS PROCEDURE AND SHOWS SAMPLE DISPLAY
- A TASK QUESTION IS SELECTED BY EXPERIMENTER ( $\Delta$ MAX OR $\Delta$ MIN )
- TESTING STARTS WITH PRESENTATION OF FIRST DISPLAY
- IF INCORRECT ANSWER IS GIVEN, EXPERIMENTER SAYS "NO" AND DISPLAY IS REPEATED
- IF CORRECT ANSWER IS GIVEN, SLIDE PROJECTOR IS ADVANCED AND NEXT DISPLAY IS REPEATED
- A TOTAL OF 24 HORIZONTAL AND 24 VERTICAL DISPLAYS ARE SHOWN IN ALTERNATING GROUPS OF 8 EACH
- FORMAT TYPES (A,B,C,...H) ARE RANDOMLY ORDERED IN EACH GROUP OF 8
- AFTER THE 48 TRIALS, PROJECTOR IS RESET AND THE REMAINING TASK QUESTION ( $\Delta$ MAX OR $\Delta$ MIN) IS ISSUED AND THE ABOVE PROCEDURE IS REPEATED
- AFTER THE SECOND 48 TRIALS, THE PROJECTOR IS RESET AND THE HI/LO TASK IS EXPLAINED
- 8 HORIZONTAL AND 8 VERTICAL DISPLAYS ARE PRESENTED USING THE HI/LO TASK QUESTION AND THE ABOVE PROCEDURE
- SS IS SHOWN THE FORMAT EXAMPLE FIGURE FROM THE INSTRUCTION SHEETS AND ASKED FOR HIS FIRST 3 PREFERENCES (IN ORDER) AND THE FORMAT HE CONSIDERED TO BE WORST.

## RESULTS

Figure 11 provides a diagram of the 3 way completely factorial experimental design. Within each block the numerical values represent the mean score for 29 subjects. Row and column means as well as the grand mean are also shown.

Graphically the mean scores (for 29 subjects) for each format are shown in Figure 12. Data points represent the average of all three tasks in both horizontal and vertical orientation. An analysis of variance (Figure 13) indicates that, in addition to task and orientation, format was a significant single source of variation. The general impression provided by the data in Figure 12 is that, over all orientations and task type, formats G and H are somewhat less effective than the remaining six.

Separating the data of Figure 12 to show individually the horizontal and vertical cases, Figure 13 demonstrates both similarities and radical differences between the horizontal and vertical formats. Similarities are apparent in the performance of formats A, B, C, D and F. Conversely the scores for formats E, G and H show a noticeable disparity with the vertical formats demonstrating significant superiority over the horizontals. Althoug' not statistically significant for each of the eight formats, seven of the vertical formats exhibited better average scores than their horizontal counterpart.

In analyzing the overall test procedure and results, it was suggested that, since the task was very dependent on visual attributes (acuity and recognition/ response time), this factor might be a source of variation. In the absence of acuity or other visual data, subject's age (in years) was plotted against average score across all conditions.

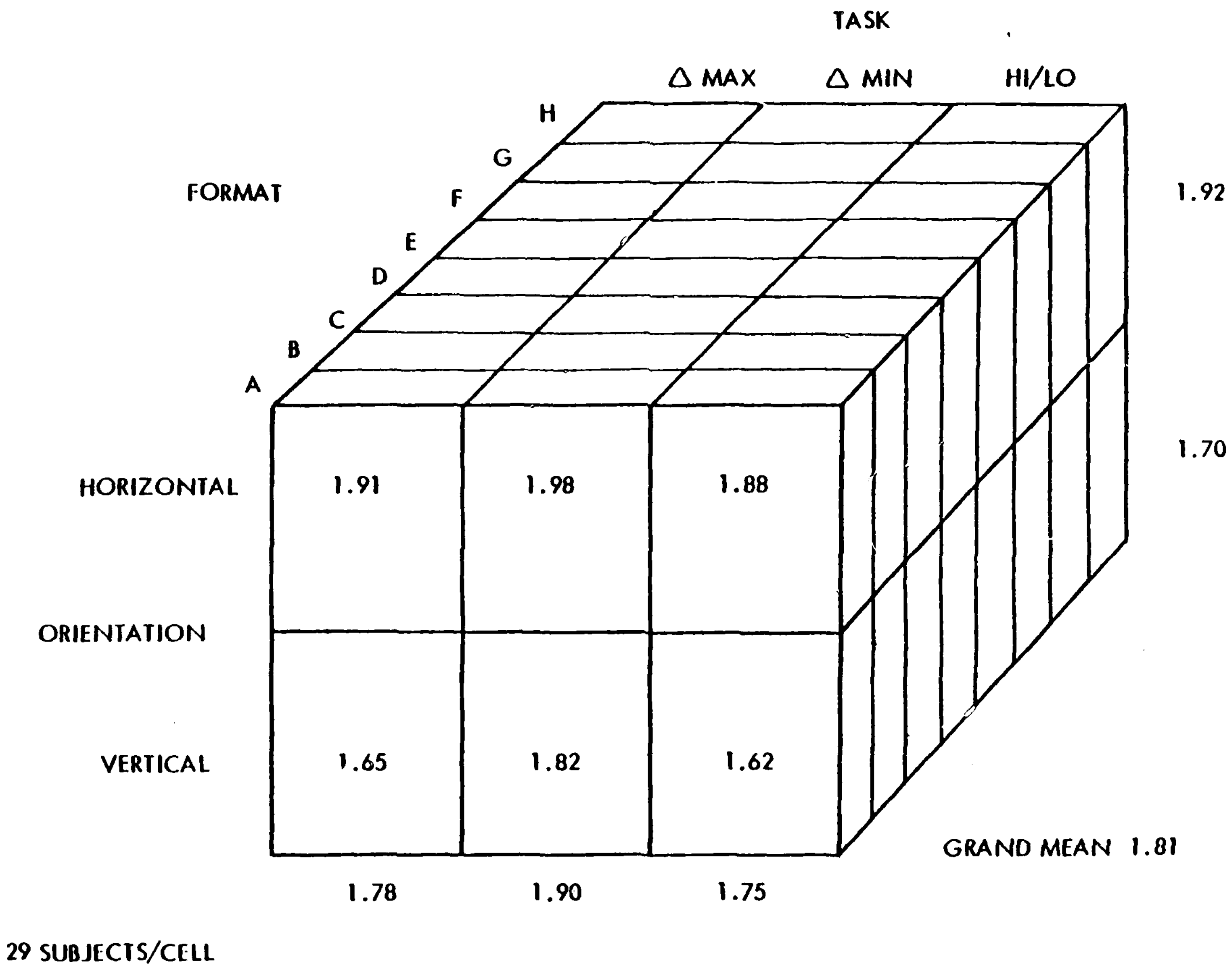

TASK
Δ MAX
Δ MIN
HI/LO
FORMAT
A
B
C
D
E
F
G
H
1.92
1.70
HORIZONTAL
1.91
1.98
1.88
ORIENTATION
VERTICAL
1.65
1.82
1.62
GRAND MEAN 1.81
1.78
1.90
1.75
29 SUBJECTS/CELL

FIGURE 11

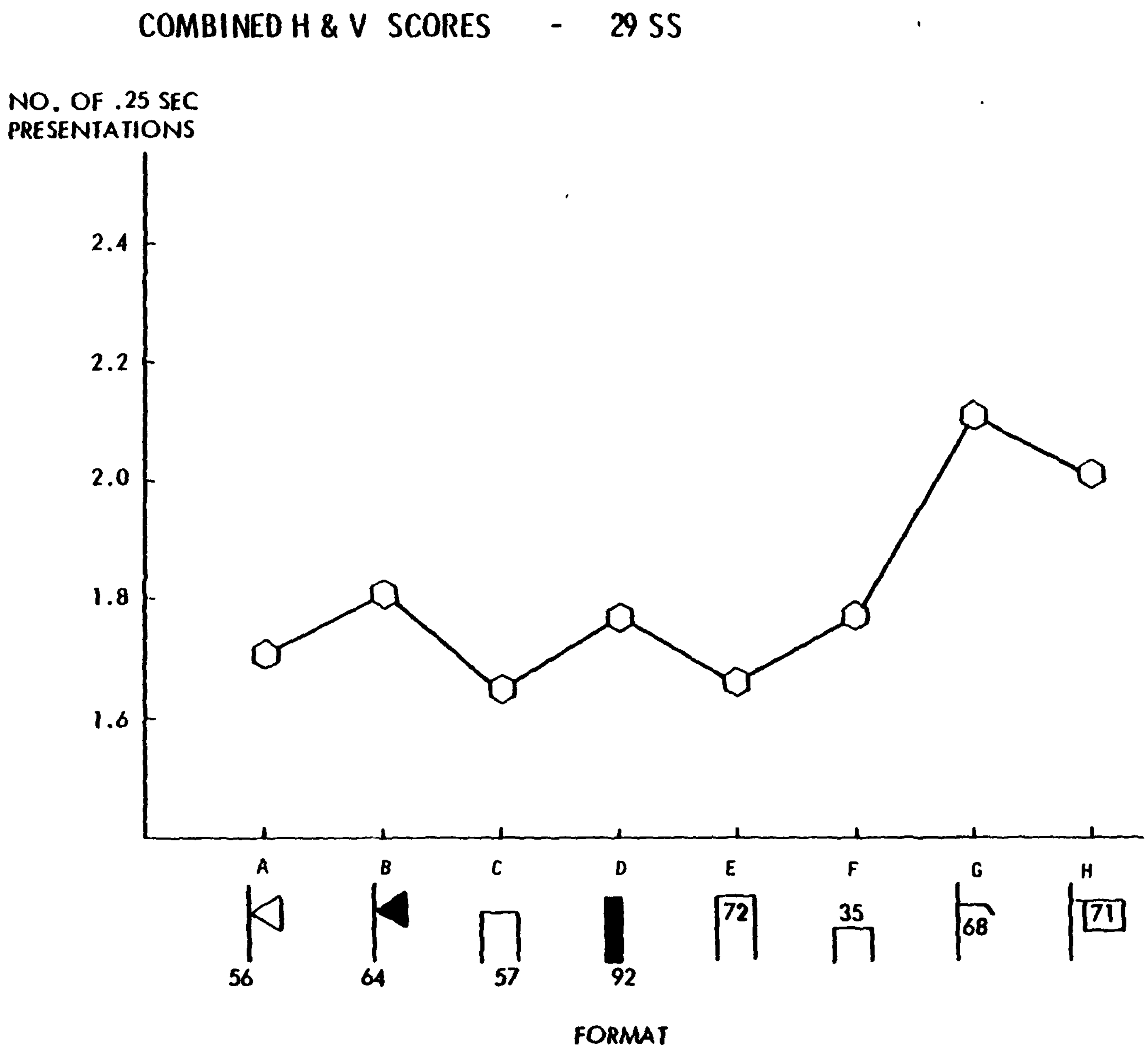

COMBINED H & V SCORES - 29 SS
NO. OF .25 SEC PRESENTATIONS
2.4
2.2
2.0
1.8
1.6
A
B
C
D
E
F
G
H
56
64
57
92
72
35
68
71
FORMAT

FIGURE 12

ANOVA - 29 SUBJECTS

| SOURCE | df | SS | MS | F | |
|---|---|---|---|---|---|
| A (TASK) | 2 | 4411.2 | 2205.6 | 802 | ($P << .001$) |
| B (ORIENTATION) | 1 | 86.0 | 86.0 | 31.3 | ($P << .001$) |
| C (FORMAT) | 7 | 210.3 | 30.04 | 10.92 | ($P << .001$) |
| AB | 2 | 15.4 | 7.69 | 2.80 | ($P \leq .05$) |
| AC | 14 | 158.2 | 11.3 | 4.11 | ($P << .001$) |
| BC | 7 | 152.3 | 21.75 | 7.91 | ($P << .001$) |
| ABC | 14 | 96.9 | 6.92 | 2.52 | ($P \leq .01$) |
| S/ABC | 1344 | 3701.7 | 2.75 | | |
| TOTAL | 1391 | 8831.9 | | | |

FIGURE 13

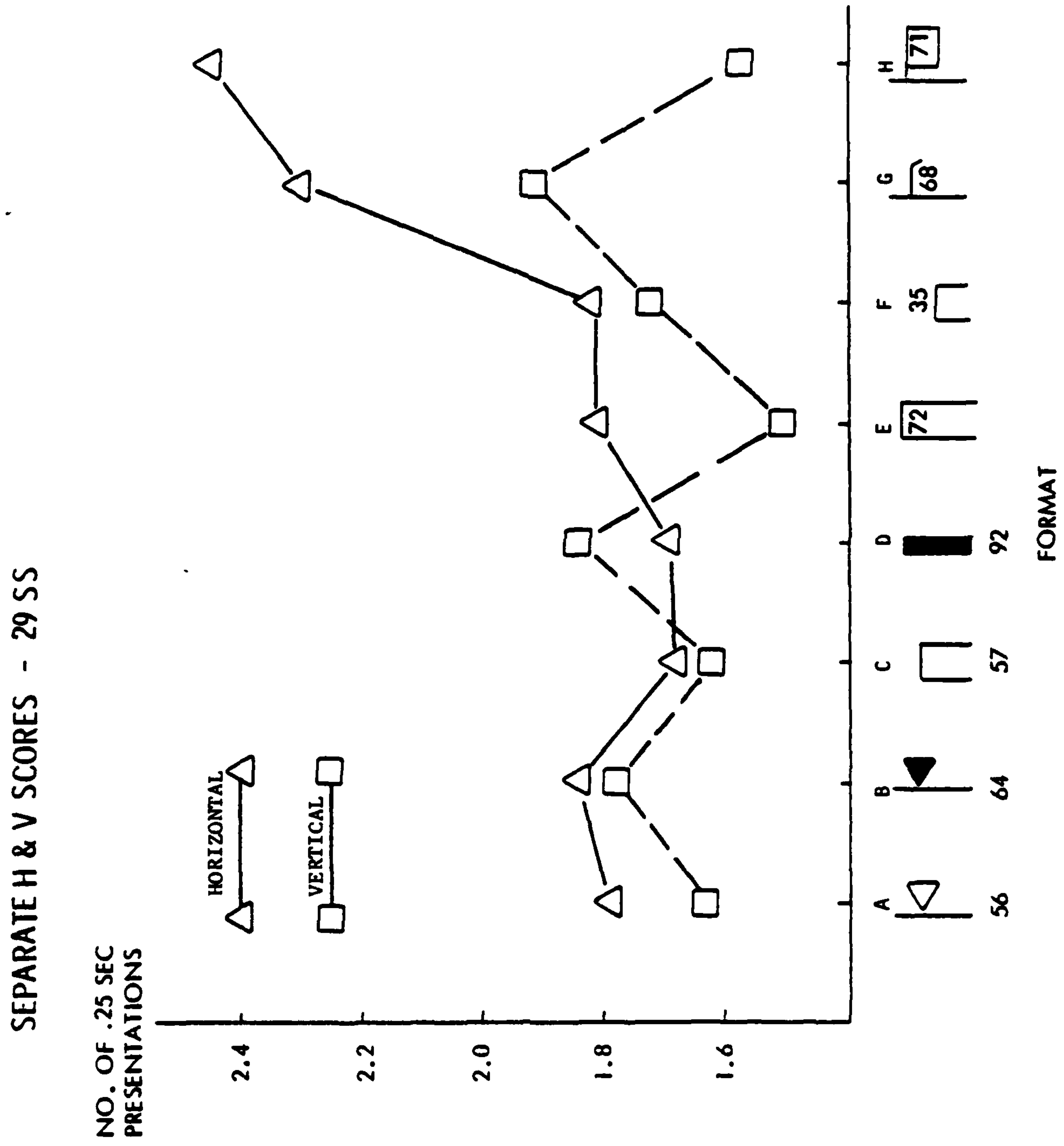

SEPARATE H & V SCORES - 29 SS
NO. OF .25 SEC PRESENTATIONS
2.4
2.2
2.0
1.8
1.6
HORIZONTAL
VERTICAL
A
B
C
D
E
F
G
H
56
64
57
92
72
35
68
71
FORMAT

FIGURE 14

The scattergram (Figure 15) and a correlation coefficient ($r < .01$) *did not* support any significant relationship. However, it is interesting to note from Figure 15 that the subjects with pilot experience (darkened data points) were all within the upper 20% of the performance range.

A subjective measure of format preference was taken at the close of each test session. Subjects indicated their first 3 choices (in order) for the format they they considered to be the easiest to read for the three tasks used in the experiment. Four of the 29 participants indicated a (first choice) preference for a horizontal format. The remaining 25 favored vertical formats in all 3 of their choices. From those favoring the vertical orientation, Format B and D were predominant as a first choice as well as in a summary of the first 3 choices. No correlation was evident in comparing (non-parametrically) subjective preference with objective test scores.

The subjective evaluations also included a preference for the worst format. Formats G and H were almost unanimous choices with no distinction given between the horizontal and vertical versions (Figure 16).

SCATTERGRAM: AGE VS. AVERAGE TEST SCORE

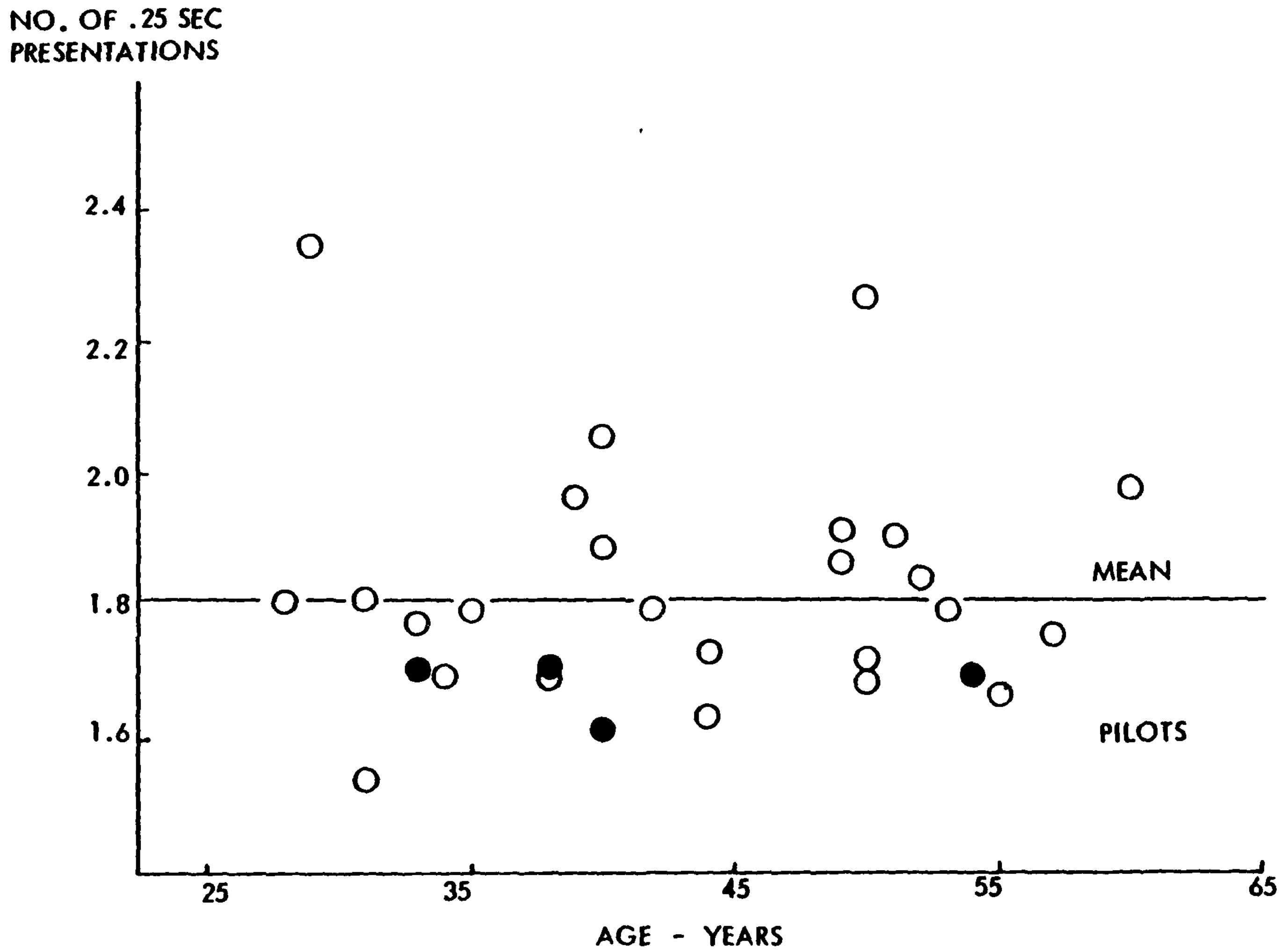



FIGURE 15

## SUBJECTIVE PREFERENCES OF FORMAT

| | HORIZONTAL 4 (14%) | | | | VERTICAL 25 (86%) | | | |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H |
| 1st CHOICE | 1 | 9 | 4 | 11 | | | | |
| 2nd CHOICE | 3 | 7 | 9 | 4 | 1 | 1 | | |
| 3rd CHOICE | 3 | 6 | 4 | 7 | 2 | | 1 | |
| SUMMARY | 7 | 22 | 17 | 22 | 3 | 1 | 1 | |
| WORST | | | | | | 2 | 11 | 12 |

FIGURE 16

## CONCLUSIONS

Several, possibly critical, factors such as information density/spacing, display size/quality, etc. were beyond the scope of this investigation and consequently were not included as part of the parametric evaluation. To account for and/or reduce the effects of, these factors, two techniques were used. Certain factors relating to information density were selected to be representative of EMMADS display requirements. Other factors pertaining to image quality were optimized to suit the task and environmental conditions. Results from the HFE Basic Testing are not intended for generalization to all analog/digital data displays, but should serve as a design guide for specific EMMADS applications. As such, the following conclusions are drawn for application to EMMADS format designs.

- In general, vertical (tape/bar) formats are recommended over horizontal configurations of four or more parameters
- Several pointer designs and bar configurations appear to provide equal operator performance
- With the exception of Format G, the location of the digital value adjacent to or within the analog element does not appear to influence performance
- Subjective preference for a format does not necessarily correlate with operator performance for the reading/interpretation tasks used herein.

- The results of all basic testing provide an overall validation of these techniques of analog/digital data presentation. The exposure time of 250 msec is significantly less than the nominal time generally allocated to such a data interpretation task, thus the range of scores (1.51 to 2.32) and the grand mean of 1.81 exposures suggest that all formats were relatively effective in providing readable information to the user.

  Recommendations for further testing are presented in a later section of this report.

## SECTION VI - CONTROL/DISPLAY FORMATS

At this point in the HFE Program, a definition of the necessary control and display capabilities and their functional interrelationships was generated. This definition was based on the results of all HFE Program efforts to date including collaborative activities with Systems Engineering. This description of the necessary control, display and functional requirements includes:

- Control Hardware
- Display Hardware
- Display Formats
- Control/Display System Function

A schematic summary of the HFE Program (Figure 17) is included as an overview. This diagram of HFE program activities, including major program tasks and their logical relationship with each other, demonstrates the overall methodology used to derive the necessary control/display format and functional relationship definitions.

Based on the results of the Basic Testing and on inputs from Systems Engineering (preliminary operational system specification), final formats were generated. Application of the Control/Display Design Criteria (Section VII) to the display formats will provide a scaling factor which will enable a specification of display size based on information content and format.

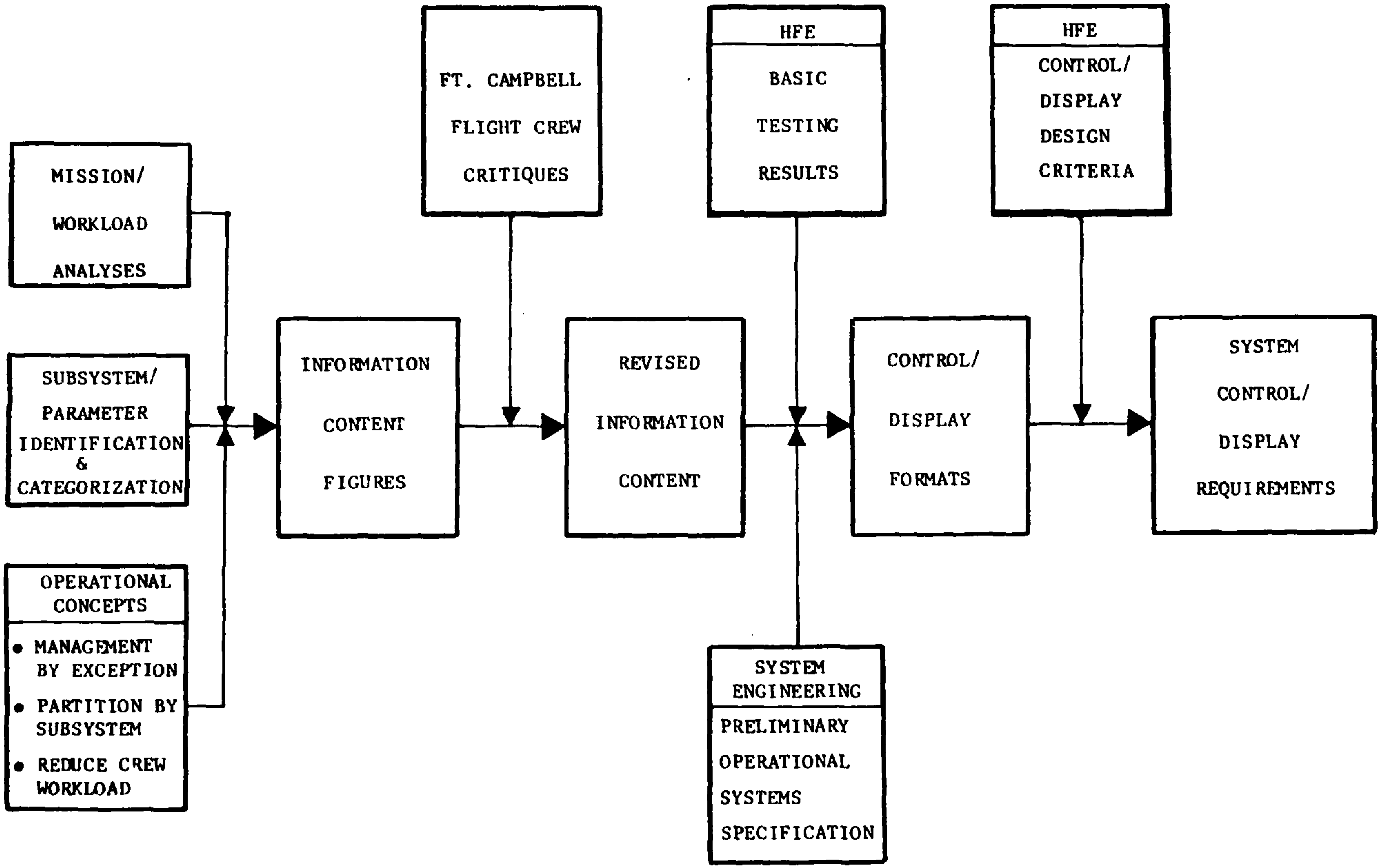



FIGURE 17
SCHEMATIC SUMMARY OF EMMADS HFE PROGRAM

System control requirements were determined primarily by the decision to partition displayed information by subsystem. Design considerations were driven by the overall system goal of workload reduction along with the provision of manual interrogation capability. A description of control requirements will follow.

DISPLAY FORMATS

The results of the Information Requirements Analyses combined with operational systems functions concepts and the recommendations of the Basic Testing Program provided necessary components for the definition of information handling formats. The following features were incorporated into the format designs:

- Continuous display of flight critical parameters (Rotor RPM and Engine Torque) and a (quasi) mission essential indication (fuel time remaining) in a prominent, dedicated display location.
- Dedicated display area for the presentation of Warning Message Capsules. A "safety of flight" priority system will determine the order of presentation for simultaneous occurrences. Several alternatives are considered for the total/simultaneous number of message capsules to be available for display. A discussion of these alternatives will follow.
- Dedicated display area for the annotation of faults (or their subsystem) which have been displayed and, by crew acknowledgement, have been removed from the display. Also the indication of those faults whose display is pending because of multiple simultaneous occurrences.

- Dedicated display area for presentation of a digital countdown and the corresponding parameter. This countdown would display the "allowable" time remaining in an "out of limits" condition, e.g. overtorque.
- Time-shared display area for the presentation of a) subsystem raw data and/or b) emergency procedures, c) routine operational checklists, d) performance checks and e) during or in-flight maintenance related parameter excursion summaries.
- The display of crew-entered data such as OAT, Gross Weight, Time of Day, etc.

Figures 21 through 45 show full scale representations of proposed EMMADS CH-47 data formats. For this report it was not practical to include a pictorial description of every fault condition, message capsule, emergency procedure, etc. As summarized in Table 5, all basic subsystem formats, two worst-case subsystem displays, faulted conditions for each subsystem, and start sequence checklists are included.

CONTINUOUSLY DISPLAYED DATA

The primary display format (Figure 21) includes a horizontally oriented analog/digital presentation of rotor RPM (top) and engine torque (bottom) and a digital display of (fuel) time remaining. The display of these data is initiated when either engine successfully starts and remains continuously displayed, in the location shown, until shutdown.

TABLE 5: SUMMARY OF INCLUDED EMMADS DISPLAY FORMATS

| FIGURE NUMBER | DESCRIPTION |
|---|---|
| 21 | PRIMARY DISPLAY |
| 22-27 | BASIC SUBSYSTEM DISPLAYS |
| 28 | WORST CASE ENGINE DISPLAY |
| 29 | WORST CASE FUEL DISPLAY |
| 30-31 | FAULTED CONTINUOUS DISPLAYS |
| 32-34 | FAULTED ENGINE DISPLAYS |
| 35 | PRIMARY DISPLAY WITH ACKNOWLEDGED FAULTS |
| 36 | FAULTED TRANSMISSION DISPLAY |
| 37 | FAULTED FUEL DISPLAY |
| 38 | FAULTED HYDRAULIC DISPLAY |
| 39 | FAULTED ELECTRICAL DISPLAY |
| 40-45 | APU START SEQUENCE DISPLAYS |

On the rotor RPM scale, two "TIC" marks indicate the normal operating RPMs of 235 and 245. "Beyond normal operating range" indications are provided by outlined warning areas at the left (low) and right (high) ends of the scale. A dual plateau is used at the high end to indicate the 5 minute and 5-sec excursion limits. These warning areas become solid (completely illuminated) when the pointer enters the defined area. Figure 30 shows this situation at the high end, i.e. rotor overspeed. Note that this condition is accompanied by the display of a countdown and parameter designation.

The torque indicator operates in a similar fashion and has a warning area only at the right (high ) end of the scale. The illuminated warning area is shown in the overtorque diaplay of Figure 31. Since torque is measured and displayed for both engines, separate indicators (with engine 1/2 notation) are necessary for "split-torque" indications. An example is shown in Figure 32 where a torque split is symptomatic of a beep trim failure.

Fuel time remaining, in digital form, is located in the upper right of the display. Display of this parameter is also initialized by the successful start of an engine and remains continuously displayed until shutdown. Discretely redundant with this fuel time countdown, a fault message also signals that X-minutes of fuel remain. The time value for this warning may be preset by the flight crew as part of the pre-flight procedures.

MESSAGE CAPSULES

As a replacement of the function of the present-day caution/warning panel, one of the responsibilities of EMMADS is to provide "specific" caution/warning information to the crew. It is assumed that "generic" alerting will continue to be provided (visually) by the master caution light. (The use of redundant audio warning cues has been suggested for EMMADS implementation. This topic will be addressed in a later section.)

Abbreviated descriptions of fault situations (similar to the legends on todays caution-warning panel) are proposed for use in EMMADS in the form of Message Capsules. These epigrammatic descriptions would provide specific information in textual form. Functionally, this fulfills the informational needs of the pilot/copilot immediately after the master caution light (and/or audio cue) has attracted his/her attention. This statement of "what" the problem is, initiates a diagnostic mental routine by the operator. Information regarding the degree, rate, or magnitude of the problem is then needed along with the status/interrelationship of other parameters. (This data would be extracted from the raw subsystem data portion of the display.)

To accommodate the "problem description" responsibility of EMMADS, a dedicated display area is provided for the presentation of Message Capsules. The allocation of display space for these message capsules is obviously contingent on the number of characters per capsule and the maximum number of capsules to be displayed simultaneously. The later of these is presently without a quantitative solution. The following factors were addressed in arriving at alternative solutions to the "Message Capsule Problem".

- The simultaneous occurrence of more than one fault in more than one subsystem is not uncommon, especially during combat.
- Inadequate display area for fault indications "hides" possibly critical data thus creating an information bottleneck at the display.

* Time sharing of display area/manual selection of data via pushbuttons are incompatible with the high workload environment and inconsistent with the goals of workload reduction.

It can be soundly argued that, for single parameter faults (Oil Pressure-Lo, PTIT-High, Generator failed, etc.), a symbolic description of the fault situation is operationally adequate. Thus for certain fault conditions a textual (verbal) Message Capsule may not be necessary.

A formatting scheme compatible with the raw data formats was therefore devised to symbolically code all single parameter faults. The coding techniques were designed to draw attention to out of limits conditions/ faulted components in a non-ambiguous manner, thus providing the same information as a textual message capsule.

For bar-type analog presentations, "out of limits" conditions are indicated by filling-in or totally illuminating the interior of the bar. For scale and pointer formats,"beyond limits" is indicated by enlarging (X2) and totally illuminating the interior of the pointer. Increasing or decreasing trend data is indicated in a similar fashion in that the symbol would become larger and would become striped (with alternate light and dark bars). The triangular pointers could also change shape or orientation to indicate direction of change. Examples of candidate techniques for these display format codes are shown in Figure 18.

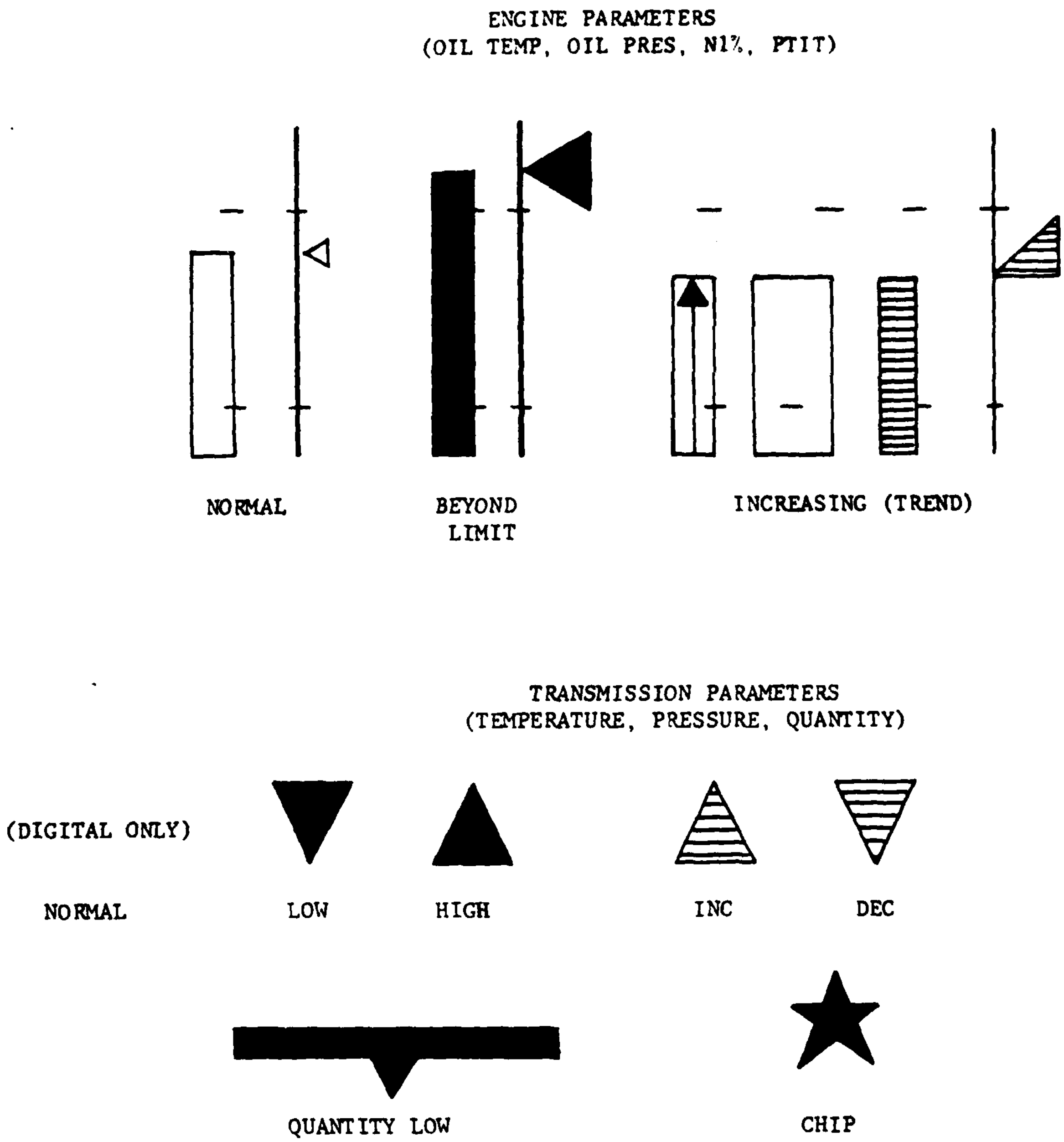



FIGURE 18
"OUT OF LIMIT" SYMBOLOGY

Since "safety-of-flight" is the ultimate consideration in any critical information management tradeoff, a (message capsule) priority system was implemented based on this consideration. This system would prioritize, via display location (top to bottom, etc.), or by symbology, the messages being displayed, or in high multiple fault situations where insufficient display area was available, would display only those messages requiring immediate crew attention.

Such a priority system was developed by Systems Engineering and is described in the Preliminary EMMADS Operational Specification. This system allocates all faults to warning, caution/precaution, or advisory categories in descending order of criticality. Within each category, numerical values are assigned to each fault to facilitate prioritization within the group. The contents of the "Warnings" category are summarized in Table 6.

It should be noted that each of the above techniques for handling "Message Capsule" data have limitations which continue to be dictated by available display area.

TABLE 6

SUMMARY OF WARNINGS PRIORITIZATION

| Fault | Subsystem | Priority |
|---|---|---|
| WARNINGS | | |
| Rotor RPM Limit (continuous display) | Powertrain | 1 |
| AGB Quill Shaft Failure | Powertrain | 1 |
| No. 1 & 2 Flight Control Hydraulic Press Limit | Hydraulic | 1 |
| No. 1 Flight Control Hydraulic Press Limit | Hydraulic | 2 |
| No. 2 Flight Control Hydraulic Press Limit | Hydraulic | 2 |
| No. 1 & 2 Engines Flamed Out | Engine | 3 |
| No. 1 Engine Flamed Out | Engine | 4 |
| No. 2 Engine Flamed Out | Engine | 4 |
| No. 1 Engine Beep Trim High Side Failure | Engine | 5 |
| No. 2 Engine Beep Trim High Side Failure | Engine | 5 |
| No. 1 Engine $N_2$ Sensing Failure | Engine | 5 |
| No. 2 Engine $N_2$ Sensing Failure | Engine | 5 |
| No. 1 Engine Beep Trim Low Side Failure | Engine | 5 |
| No. 2 Engine Beep Trim Low Side Failure | Engine | 5 |

The following alternative techniques (or combinations) are submitted for further consideration.

ALTERNATIVE 1 — Only the "Warnings" message capsules will be displayed in textual form. All other fault conditions are indicated on the appropriate subsystem raw data display. Flashing or somehow highlighting either the affected subsystem switch legend or the acknowledgement annotation in the upper left, would indicate the presence of faults not currently displayed.

ALTERNATIVE 1A — A modification of Alternative 1 such that "Warnings" will always be displayed textually with the addition that message capsules will be displayed for those subsystems whose raw data is not on display. These "pending" subsystem message capsules may not be accompanied by a subsystem indication in the upper left unless, because of excessive message capsules, no space is available. The overall system priority system would determine which message capsules would/would not appear because of space limitations.

ALTERNATIVE 2 — Same as Alternative 1 except that all message capsules would be displayed (if display space was available) with the overall priority system deciding which messages would be excluded (because of space limitations).

ALTERNATIVE 3 One message capsule "Location" would be assigned to each subsystem. All related messages would appear in that fixed location under the control of crew acknowledgement inputs.

ALTERNATIVE 4 The second crew station display would be used (in series) to handle excess message capsules, or a special (manually selected) dedicated format would be used to summarize all faults.

One general philosophy regarding the display of message capsules will be maintained. Left (Engine 1), right (Engine 2) and center (fwd, aft, unspecified) locations for message display provide a fault location indication without the need for this designation within the message. This technique is not only spatially efficient but also enables rapid interpretation "at a glance" by the crew.

The display formats which follow are representative of the message capsule approach of Alternative 2, although the number of message capusle locations, (nine :3 Eng 1 or Left, 3 Engine 2 or right and 3 unspecified) is representative of the maximum requirements of Alternative 1. Figures 28 and 29 show worst case displays with Xs designating the location of message capsules (just below the continuous display). Parameter values are purely arbitrary.

DISPLAY SYSTEM FUNCTION

A detailed description of system operation will not be addressed here but may be found in the EMMADS Operational Specification developed by Systems Engineering. However, a brief summary will be included to facilitate a better understanding of the functional relationship of the included control and display formats.

The primary display (Figure.21) shows the routine flight display with no fault conditions or manually selected data. During no-fault conditions, individual subsystem data is selectable at all times as are other options (to be discussed in the controls section). Upon the occurrence of a fault(s), a message capsule(s) is presented (Alternative 2) along with the raw data for the affected subsystem. An outline or boxed symbology is used to denote that message capsule for which the raw data is presently displayed. This helps to clarify display status when more than one message capsule is being displayed. In this case the priority system will handle simultaneous occurrences. For simultaneous fault conditions in more than one subsystem, the first message and subsystem raw data will be acknowledged by the crew to allow the display of the other subsystem raw data to occur. This acknowledgement will be accomplished via a (cyclic or collective mounted) switch during high workload conditions. Manual selection of the other subsystem could provide this crew acknowledgement during routine (non-high) workload situations. An additional panel-mounted, programmable, pushbutton could also be used. In either case an annotation of this acknowledged condition appears in a dedicated location (by subsystem name) at the upper left of the display. Acknowledgement of the last of the multiple/simultaneous faults would return the display to the primary flight display with indications of faults as shown in Figure 35.

SUBSYSTEM FORMATS

Figures 21 through 26 show basic, unfaulted conditions for the primary flight display and all subsystems. Figures 28 and 29 show the location and symbology for all possible fault conditions (except analog/digital parameter excursions) for the engine and fuel displays, respectively.

The star symbols at the left and right of the engine display indicate chip detection (Engine 1 and 2, respectively). The highlighted left, forward aux tank in the fuel format indicates tank overpressurization, while the "LO PRS" notation refers to fuel system pressure, left/right.

Selected fault conditions are shown for each of the subsystems in Figures 30 through 39. The schematic formats for fuel and transmission were used to reduce the need for labeling and to provide a degree of pictorial realism which should enhance orientation and comprehension. Although not shown in Figure 36, the high, low, increasing, decreasing symbology shown above is used when necessary within each of the transmission blocks.

## OPERATIONAL CHECKLISTS

Implementation of procedural checklists by EMMADS may be characterized by two levels of system involvement.

Checklist logic may be totally "interactive" with aircraft hardware thus enabling EMMADS to sense switch positions, parameter values, etc. and thus automate/monitor much of the checklist procedure. This would necessitate widespread aircraft sensor, control and display modifications. A less interactive approach would use the EMMADS checklist as a substitute for today's hard copy, hand held version. The provision of any (degree of) checklist capability by EMMADS must also give practical consideration to a convenient method of making modifications/updates to existing procedures.

Figures 40 through 45 show selected stages in the display of the routine APU start sequence. The checklist formats shown assume that acknowledgement of each step will be provided manually (by the crew) or automatically by the system (if practical).

The proposed procedure and format are selectively represented in Figure 40 - 43 for the first eleven steps of the APU start sequence. An outlined block designated the next step to be accomplished. Upon completion, the block moves to the next step and a verification symbol indicated acknowledgement by the crew or by EMMADS. After the last step on a page is accomplished and acknowledged, an additional acknowledgement is required to check read the status column for completeness. This task is facilitated by the contiguous symbology in that a missing symbol would be easily detected.

CONTROLS

Although a fundamental intent of EMMADS is to minimize/eliminate manual crew activity, the inclusion of pilot/copilot interaction capability in the EMMADS design facilitates certain operational/hardware/conceptual requirements. In general, optimal utility cannot be achieved with a programmable display without operator interaction. For EMMADS applications controls are required to accomplish:

- Selection of specific subsystem data during non-fault conditions (primary mode)
- Selection and implementation of secondary modes of operation such as operational procedure checklists, performance calculations, emergency procedures, maintenance data play-back, etc.

EMMADS Control requirements were driven by the need to satisfy the above operational requirements. Primary consideration was given to the requirements related to subsystem monitoring and data evaluation which might be conducted manually by the crew during low workload periods. The decision to partition data by subsystem necessitates at least six switch selection options. Some additional control is also desirable to clear the display or return to the primary condition. Also to make use of the (possibly)

programmable switch legend, some additional control is required to select different levels of switch legends. Based on these requirements and assuming the use of programmable legend, multi-function switches, the following configuration (Figures 19 and 20) of seven switches was defined. The functional design of this configuration is consistent with the requirements of primary and secondary EMMADS functions.

An operational description of the programmable, multi-function, push-button switch configuration is detailed in Figure 19.

The primary set of legends "ENG DATA", "XMSN DATA", etc. provide an alternate action function, i.e.,their selection not only effects a display change, but the selected switch is relegended to make available another selection. For example, selection of ENG DATA displays the basic engine format while the legend changes to indicate the availability of engine procedures- "ENG PROC". All levels of the switch legend definitions have not been defined. "To Be Determined" (TBD) indications are shown in Figure 19 for such undefined cases.

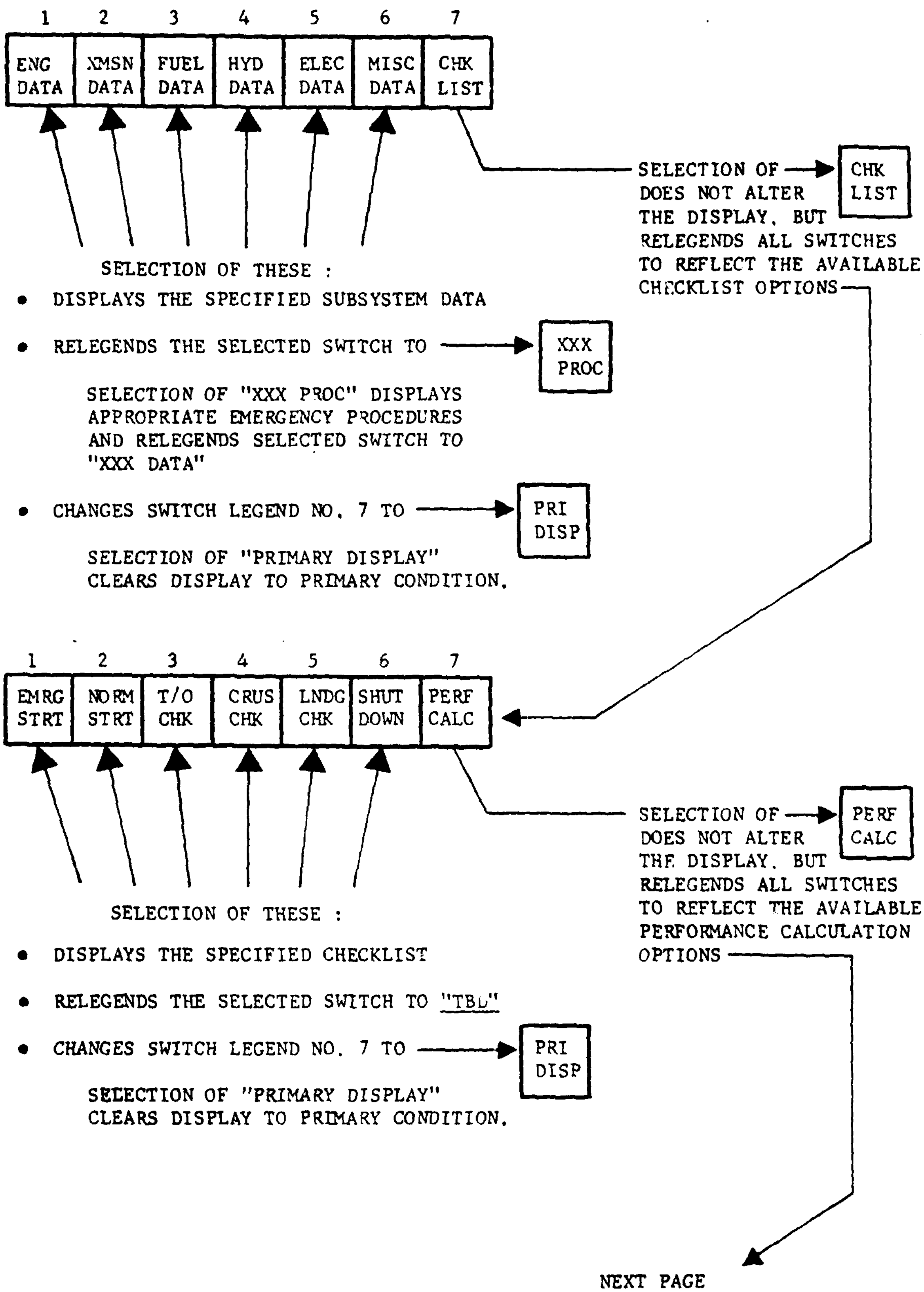
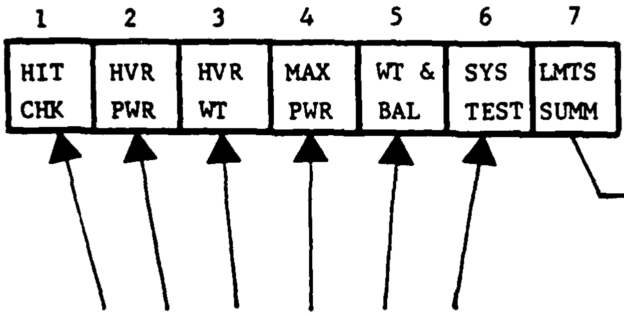



FIGURE 19

PROGRAMMABLE SWITCH LEGEND SEQUENCES




SELECTION OF → LMTS SUMM DOES NOT ALTER THE DISPLAY, BUT RELEGENDS ALL SWITCHES TO REFLECT THE AVAILABLE "TBD" OPTIONS

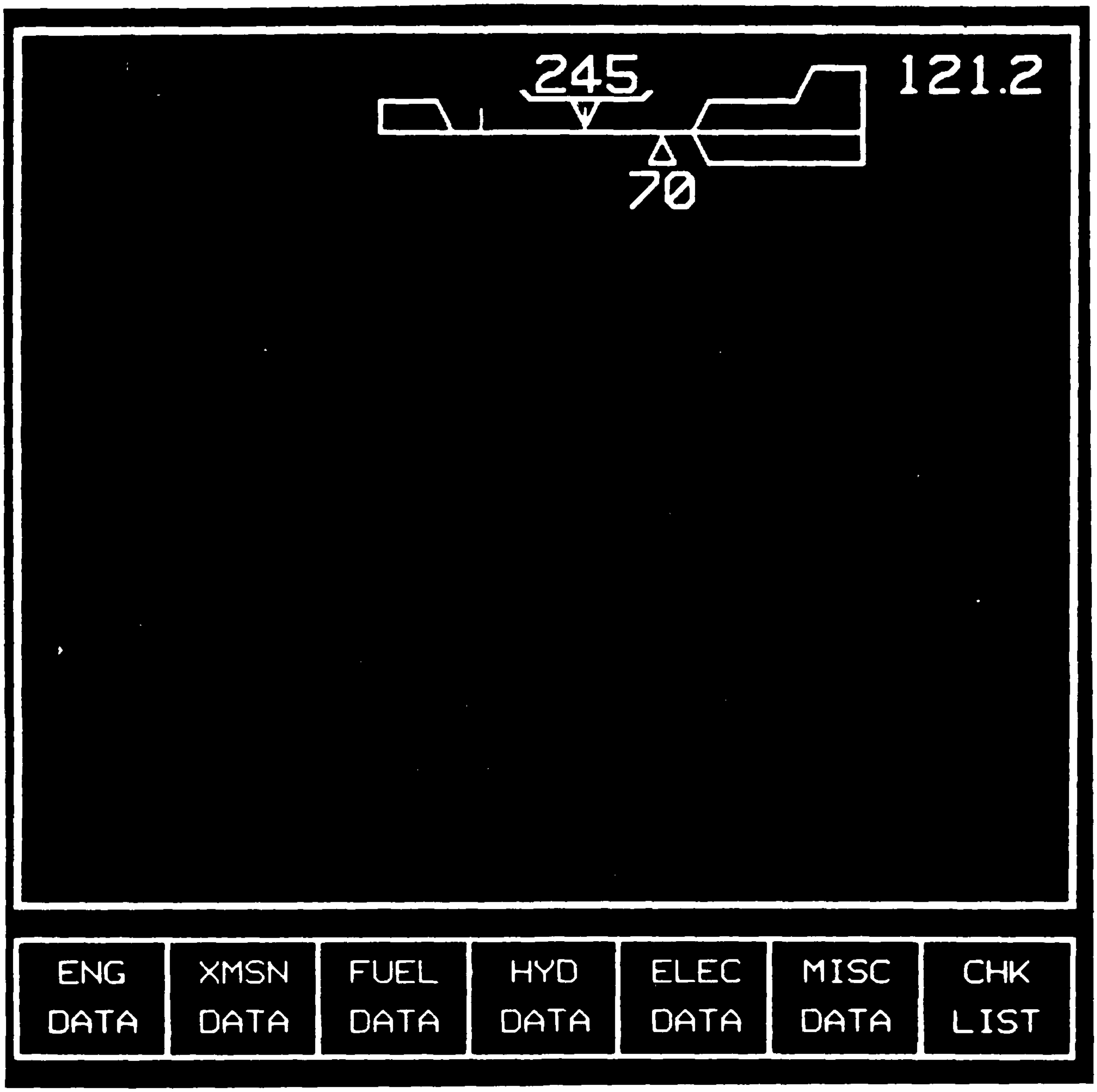
SELECTION OF THESE:

- DISPLAYS THE SPECIFIED PERFORMANCE CALC FORMAT
- RELEGENDS THE SELECTED SWITCH TO "TDB"
- CHANGES SWITCH LEGEND NO. 7 TO → PRI DISP

  SELECTION OF "PRIMARY DISPLAY" CLEARS DISPLAY TO PRIMARY CONDITION.

FIGURE 20

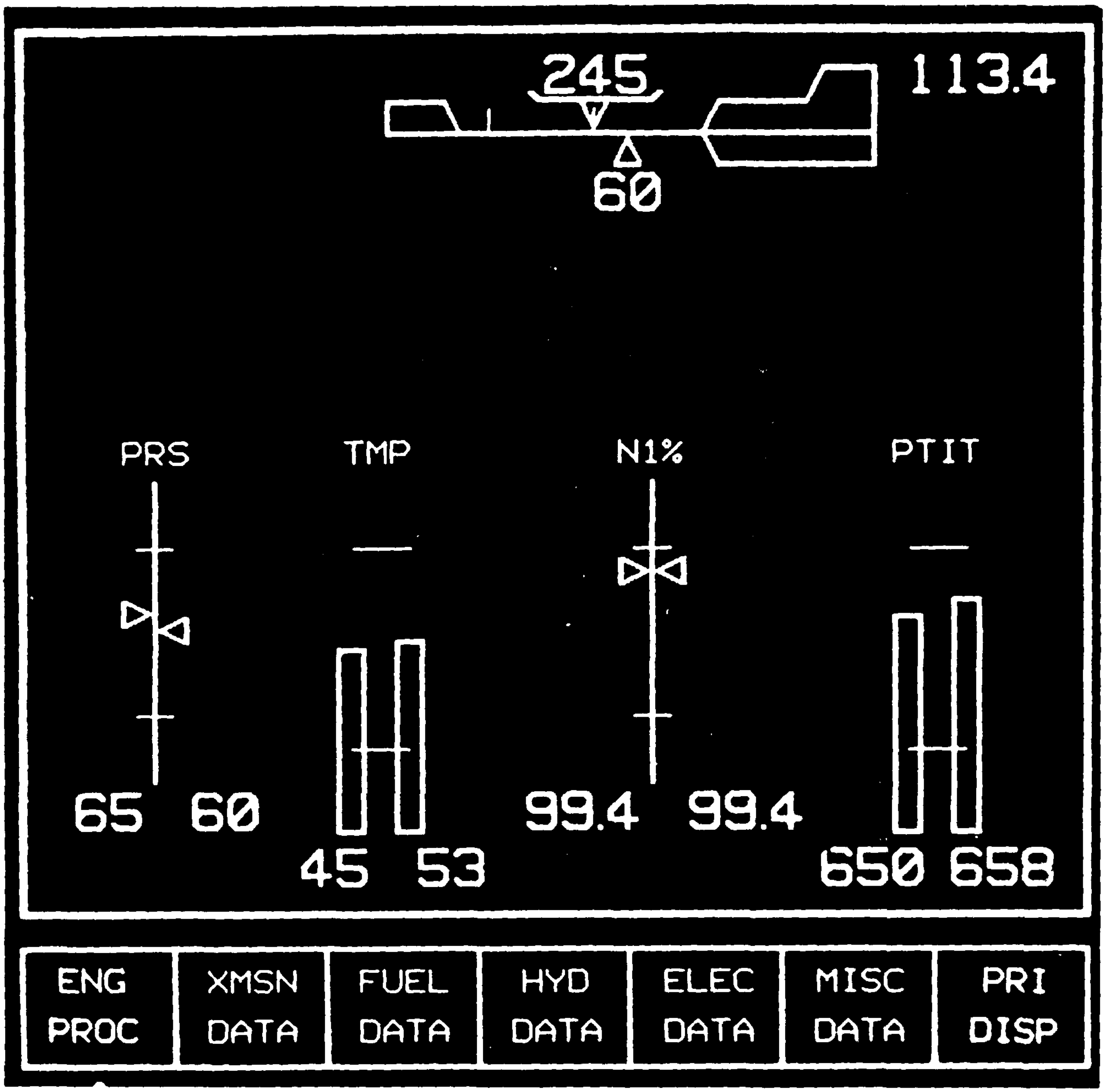
PROGRAMMABLE SWITCH LEGEND SEQUENCES




PRIMARY FLIGHT DISPLAY

NO FAULT/WARNINGS ARE DISPLAYED. ALL SUBSYSTEMS ARE AVAILABLE FOR SELECTION. THE NEXT LEVEL OF SWITCH LEGENDS IS AVAILABLE BY SELECTION OF "CHK LIST".

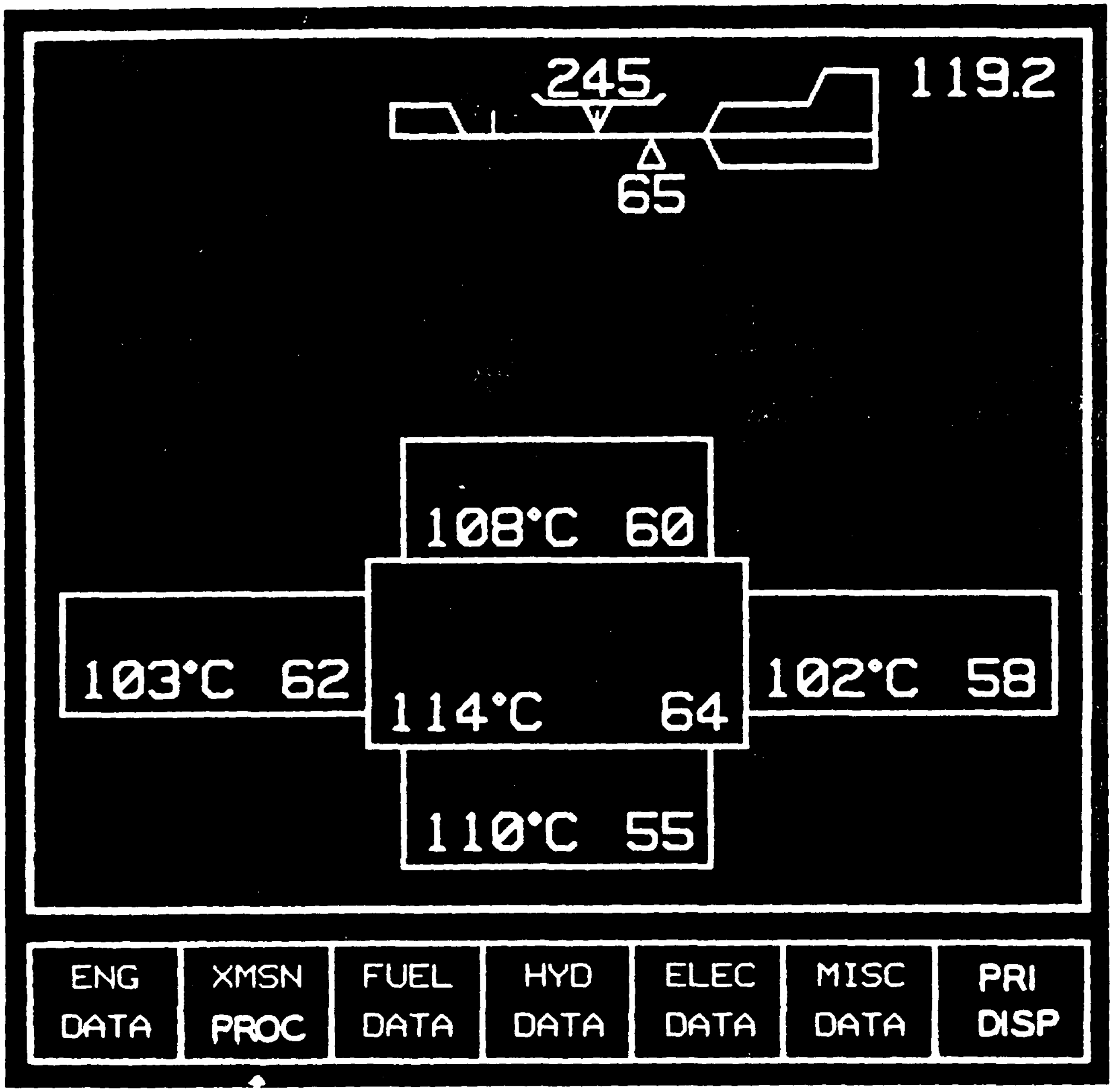
FIGURE 21




BASIC ENGINE DISPLAY

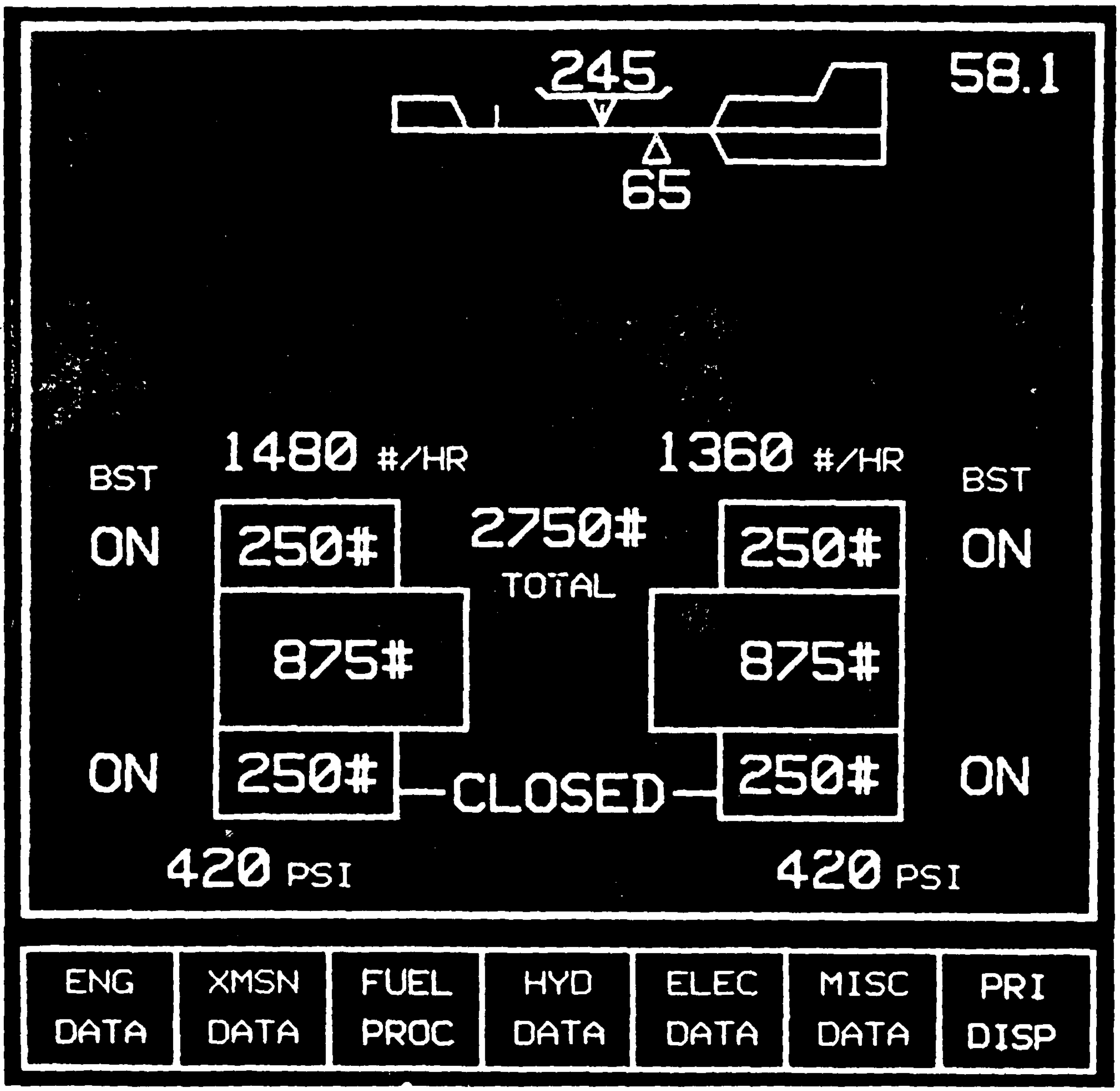
ROUTINE FLIGHT CONDITIONS ARE SHOWN. SWITCH LEGENDS SHOW THE AVAILABILITY OF THE ENGINE PROCEDURES SEQUENCES, OTHER SUBSYSTEM DATA, OR THE PRIMARY DISPLAY.

FIGURE 22



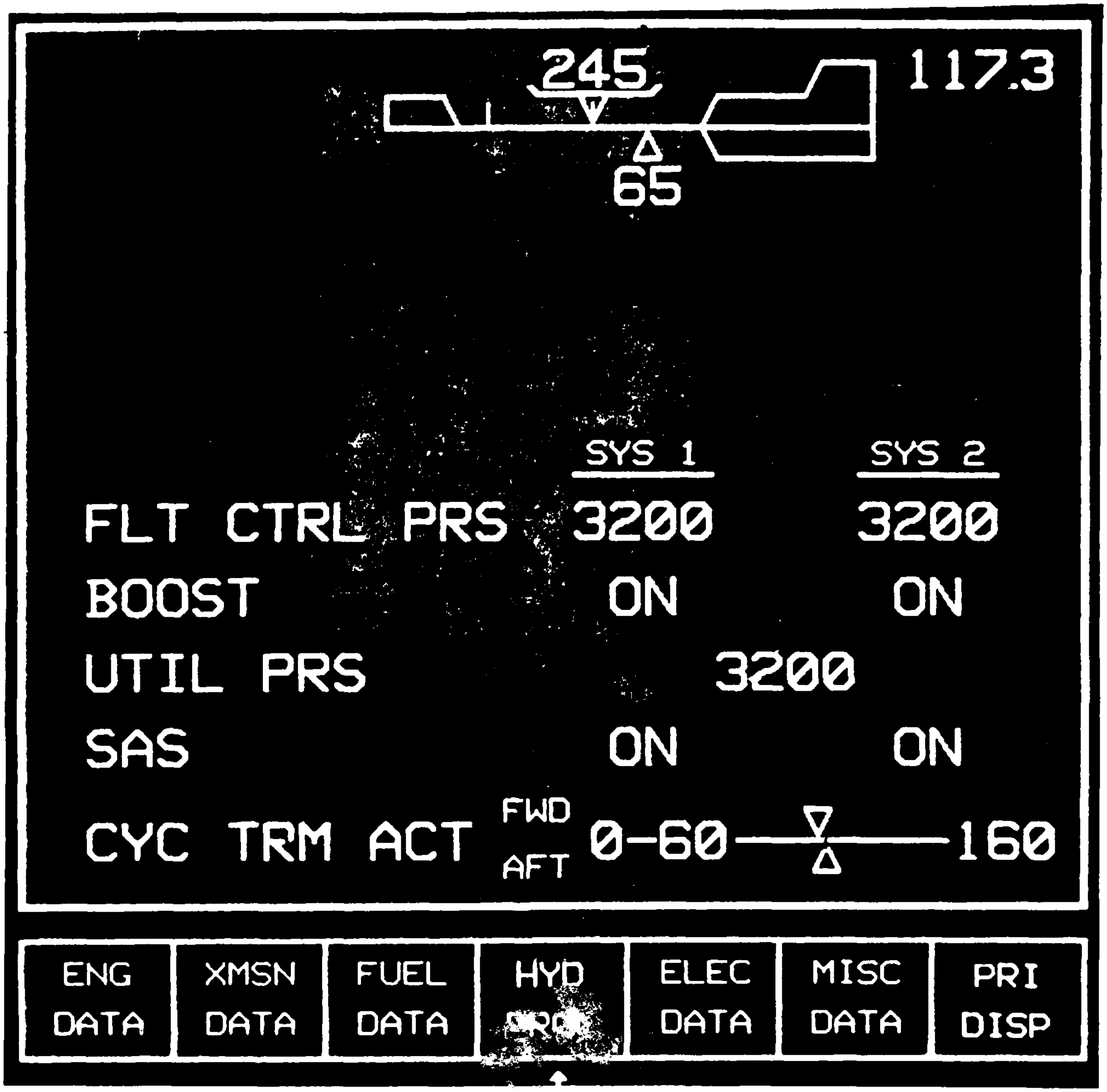

BASIC TRANSMISSION DISPLAY

FIGURE 23



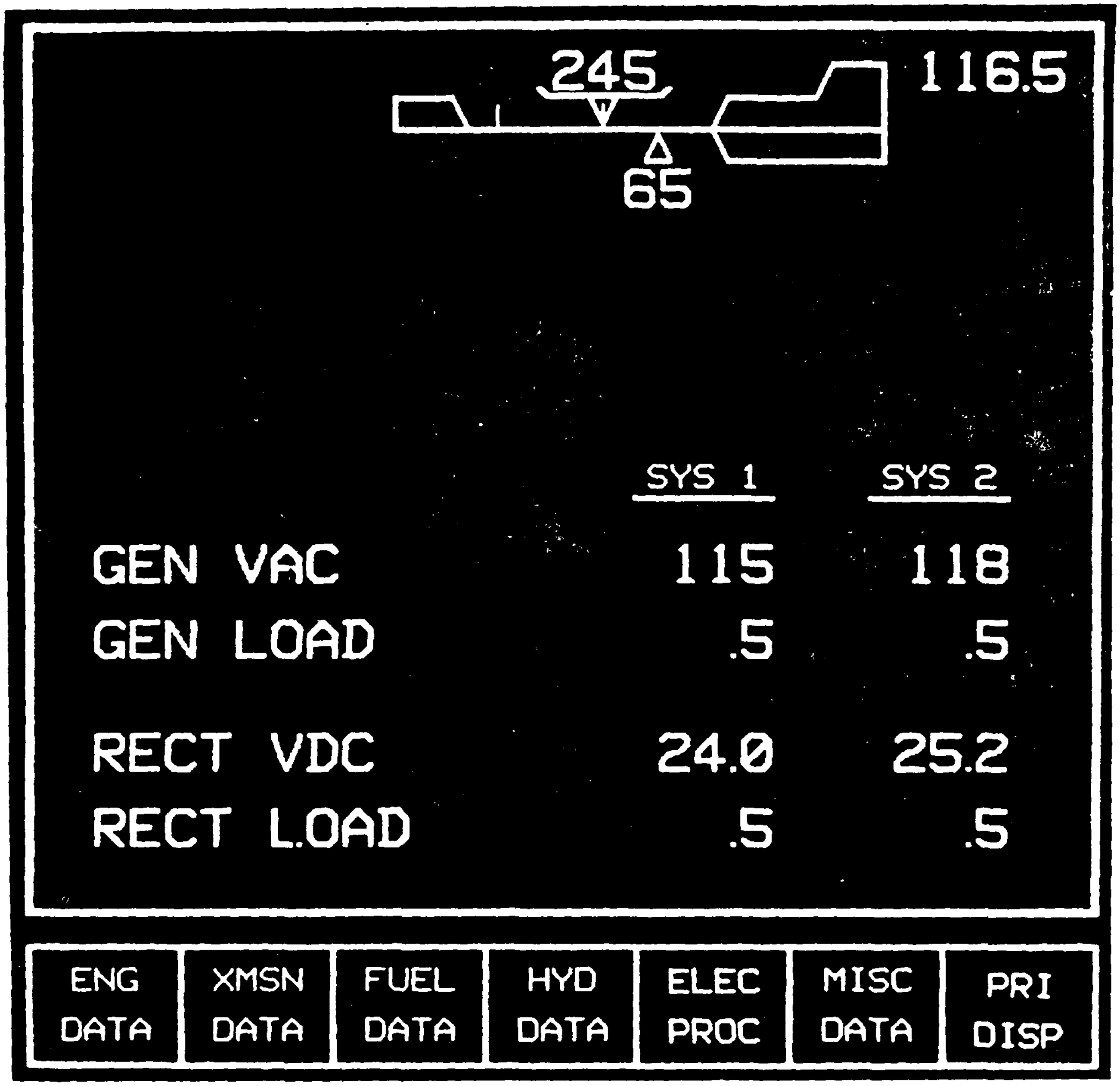

BASIC FUEL DISPLAY

FIGURE 24



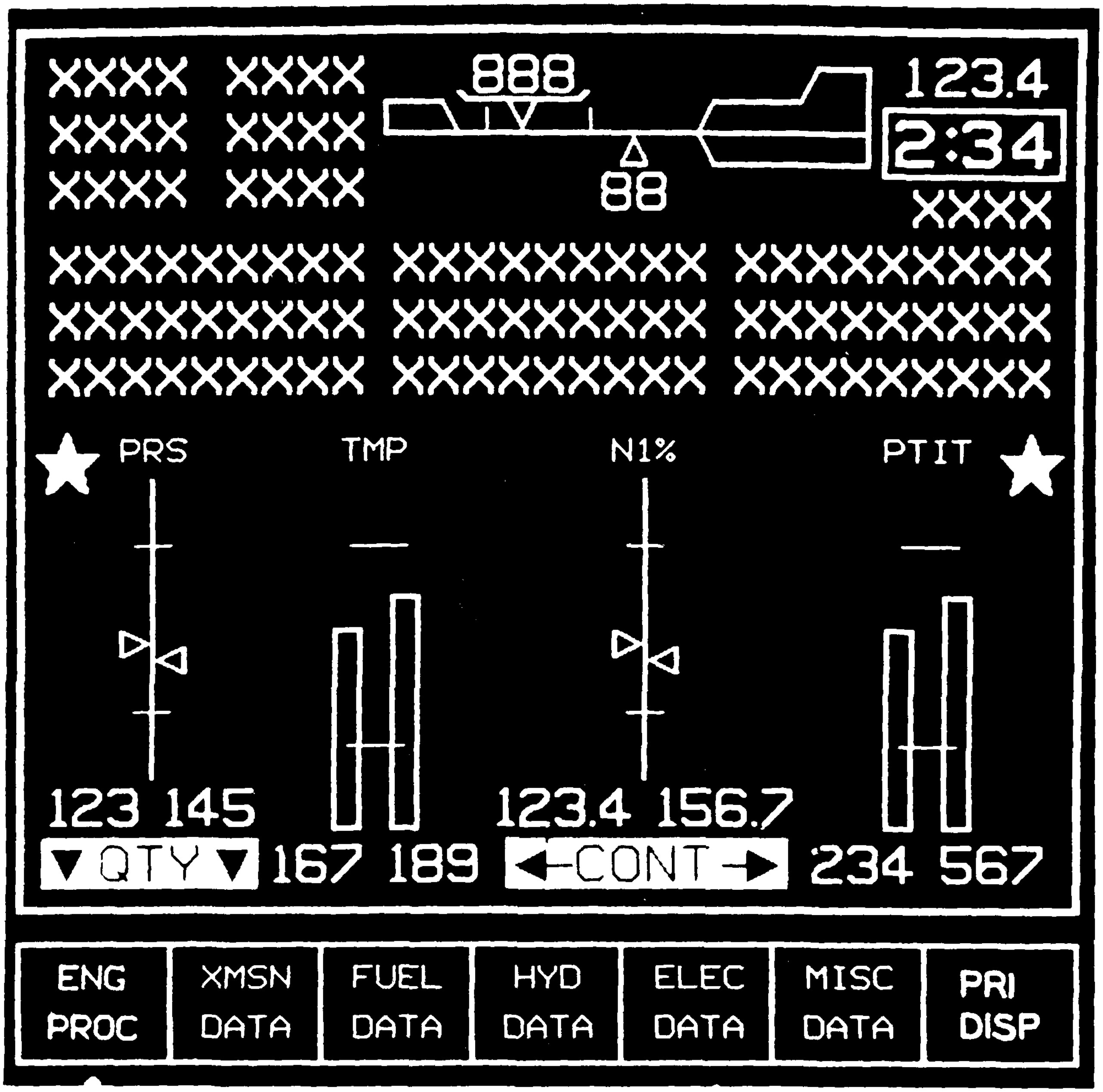

BASIC HYDRAULIC DISPLAY

FIGURE 25




BASIC ELECTRICAL DISPLAY

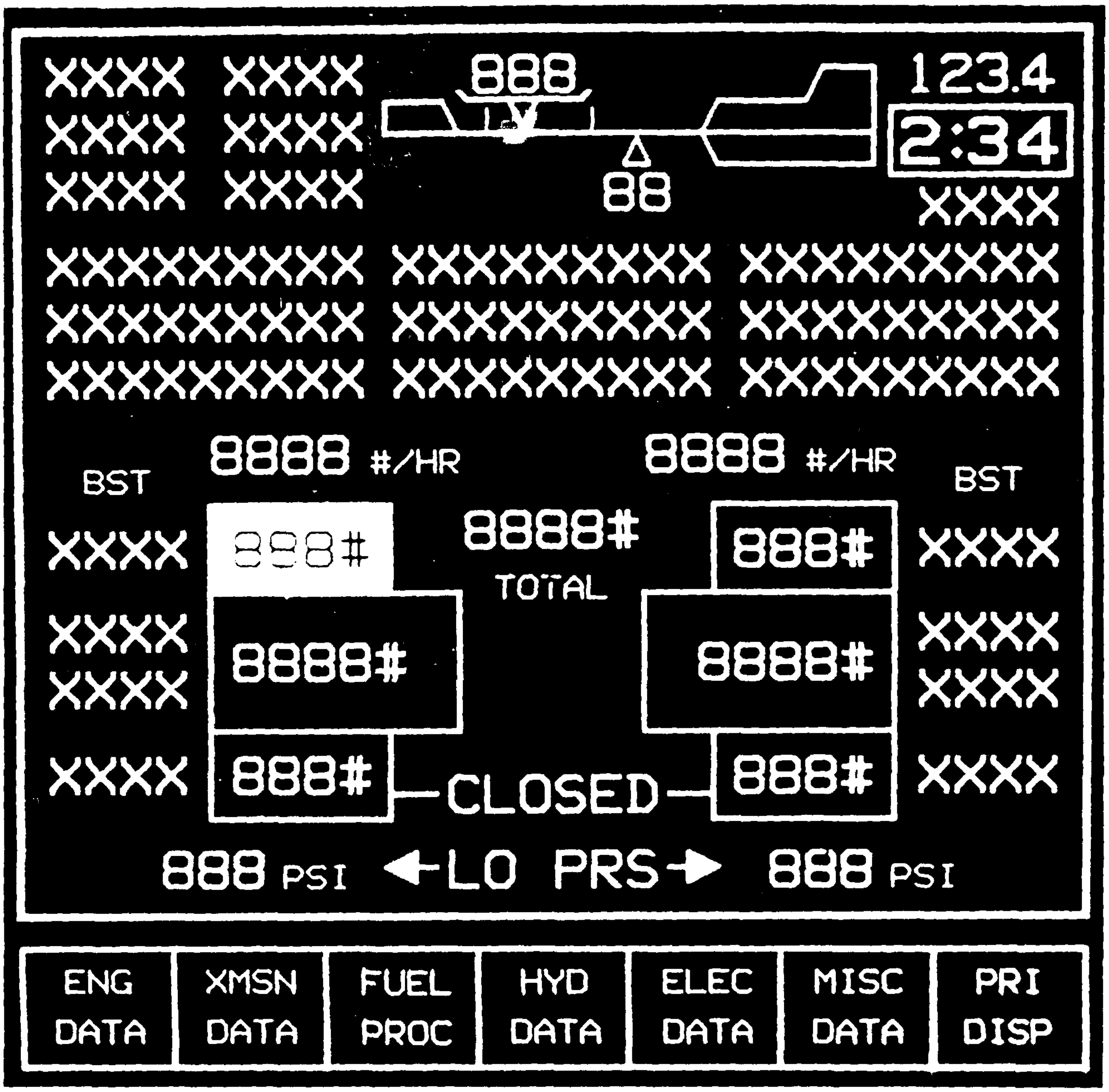
FIGURE 26




WORST CASE ENGINE DISPLAY

THE LOWER (RAW DATA) PORTION OF THE DISPLAY SHOWS THE FOUR ENGINE PARAMETERS (ANALOG AND DIGITAL) AND THE SYMBOLOGY WHICH INDICATES LOW OIL QUANTITY, N1 CONT FAILURE, AND CHIP DETECTION. ALL DIGITAL VALUES ARE ARBITRARY. SIX SUBSYSTEM POSITIONS ARE REPRESENTED IN THE UPPER LEFT. NINE MESSAGE CAPSULE POSITIONS ARE SHOWN IN THE CENTER DESIGNATION OF THE PARAMETER UNDERGOING COUNTDOWN IS LOCATED UNDER THE COUNTDOWN BOX AT THE UPPER RIGHT.

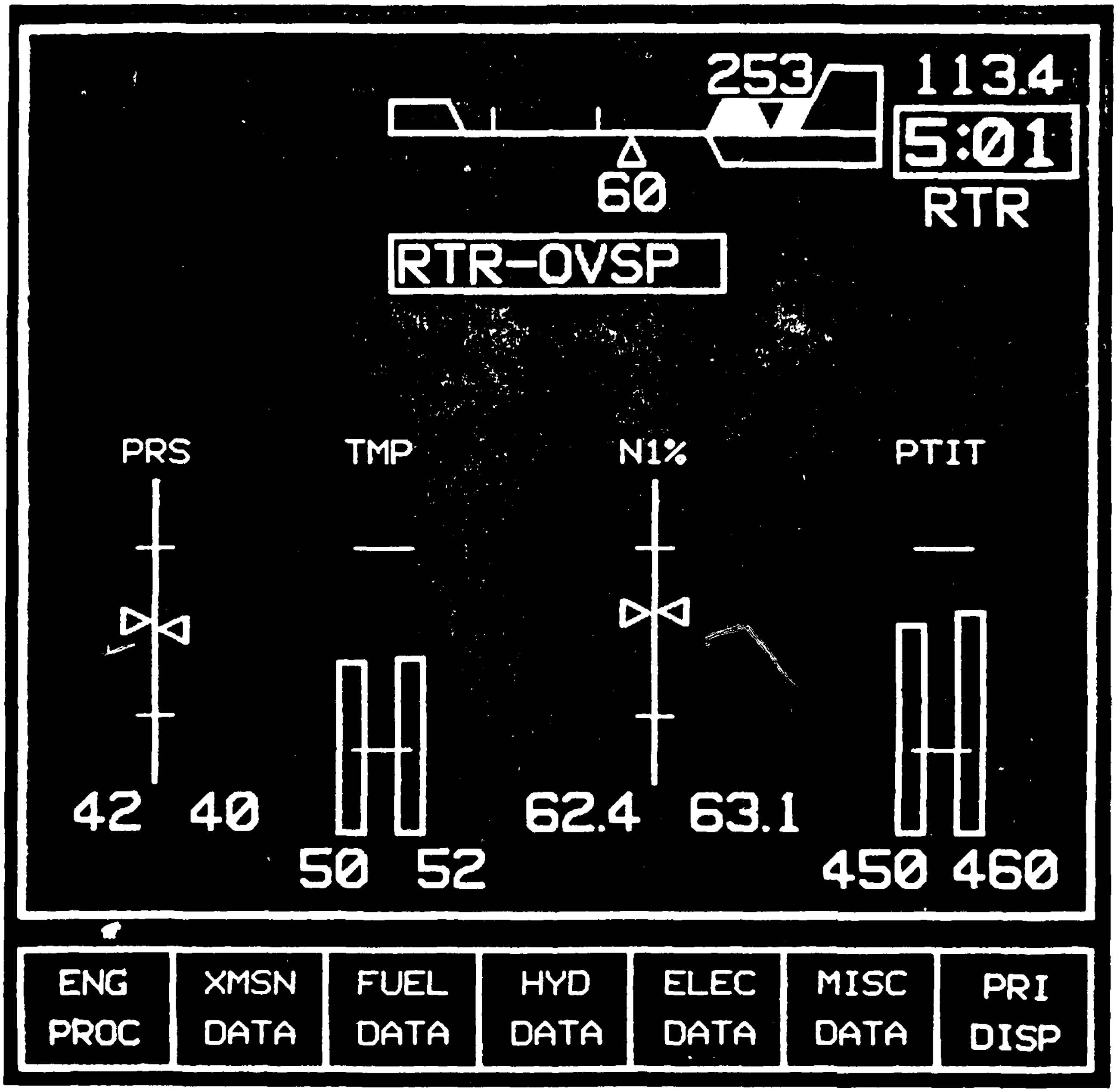
FIGURE 28




WORST CASE FUEL DISPLAY

IN ADDITION TO ROUTINE PARAMETER VALUES (FUEL QTY, FLOW RATE, PRESSURE) AND BOOST PUMP AND CROSSFIELD VALVE STATUS, SYMBOLOGY IS SHOWN FOR TANK OVERPRESSURIZATION AND LOW FUEL SYSTEM PRESSURE (RIGHT OR LEFT).

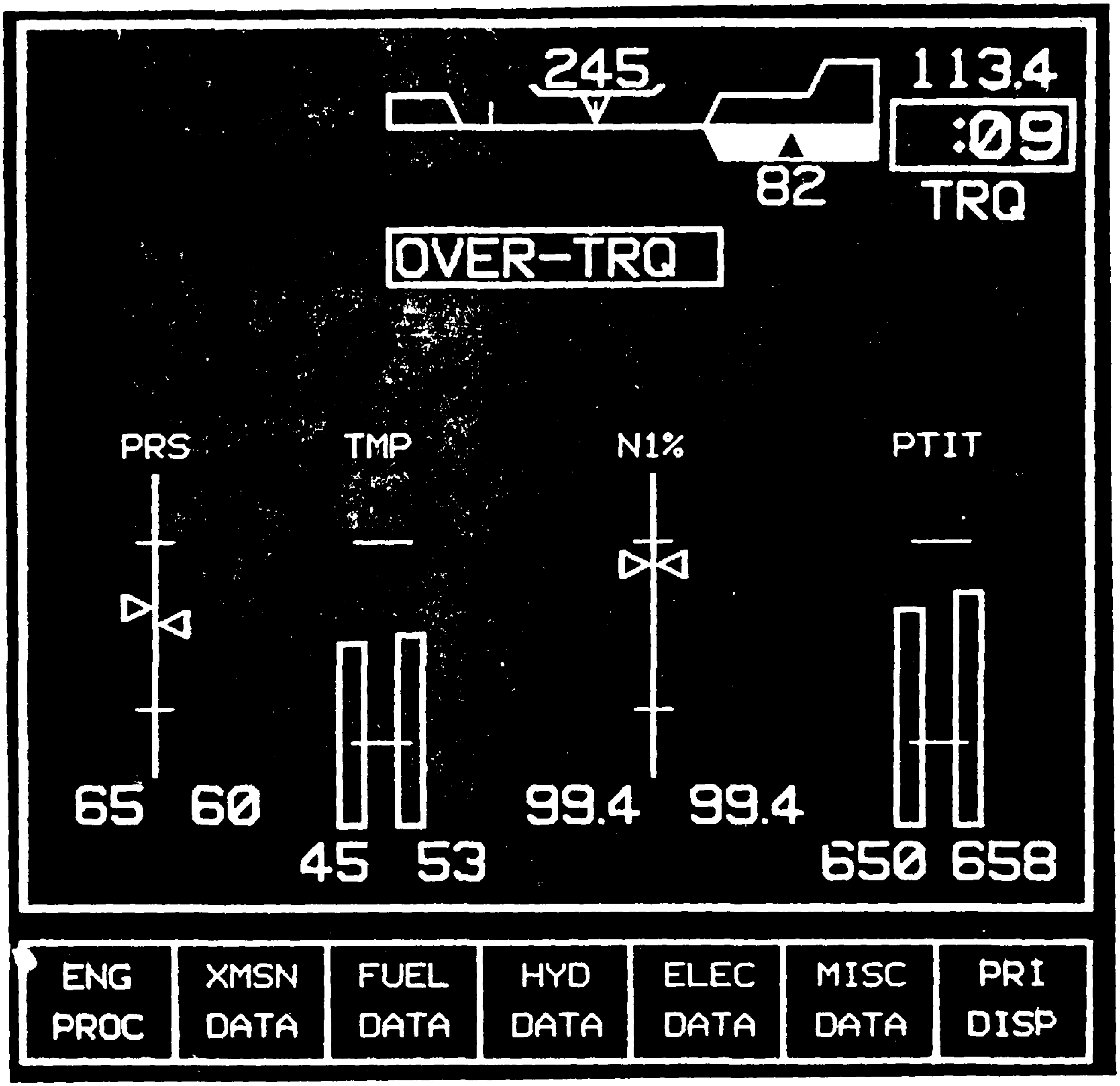
FIGURE 29




FAULTED ROTOR DISPLAY

ROTOR OVERSPEED CONDITION IS INDICATED BY MESSAGE CAPSULE AND BY HIGHLIGHTED NEGATIVE VIDEO SYMBOLOGY.
A 10-MINUTE COUNTDOWN IS ABOUT HALF ELAPSED.
RAW ENGINE DATA IS INHIBITED.

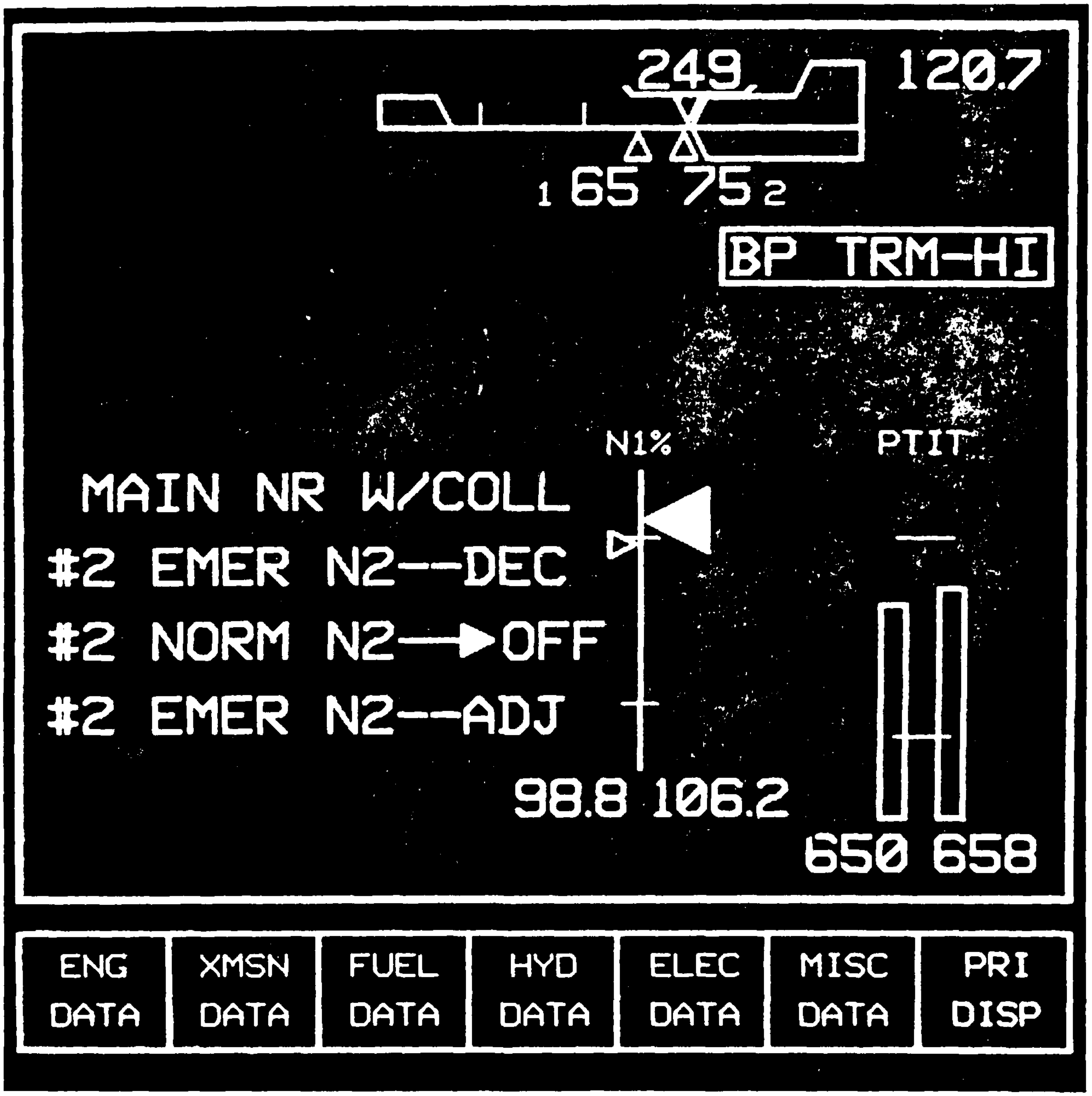
FIGURE [illegible]




FAULTED TORQUE DISPLAY

TORQUE VALUE BEYOND NORMAL LIMITS IS INDICATED BY MESSAGE CAPSULE, OUT OF LIMITS SYMBOLOGY, AND TORQUE COUNTDOWN. ENGINE DATA IS INCLUDED.

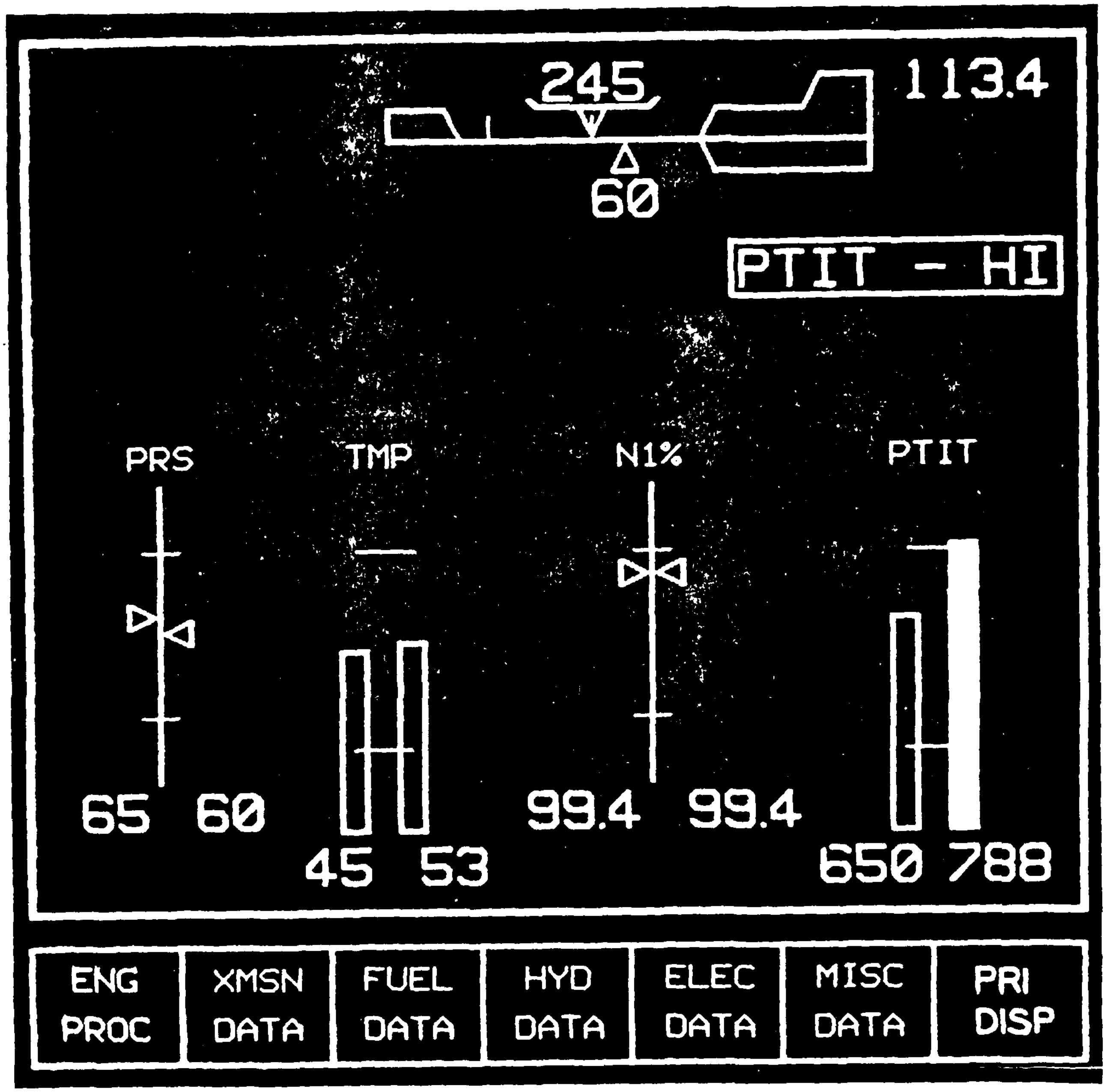
FIGURE 31




FAULTED ENGINE DISPLAY WITH EMERGENCY PROCEDURES

BEEP TRIM FAILURE (HIGH SIDE) IS INDICATED BY MESSAGE CAPSULE AND SYMPTOMATIC CONDITIONS IN THE ENGINE, ROTOR AND TORQUE DATA.
THE CRITICALITY OF THIS FAILURE DICTATES THE SIMULTANEOUS PRESENTATION OF EMERGENCY PROCEDURES AND RAW DATA.

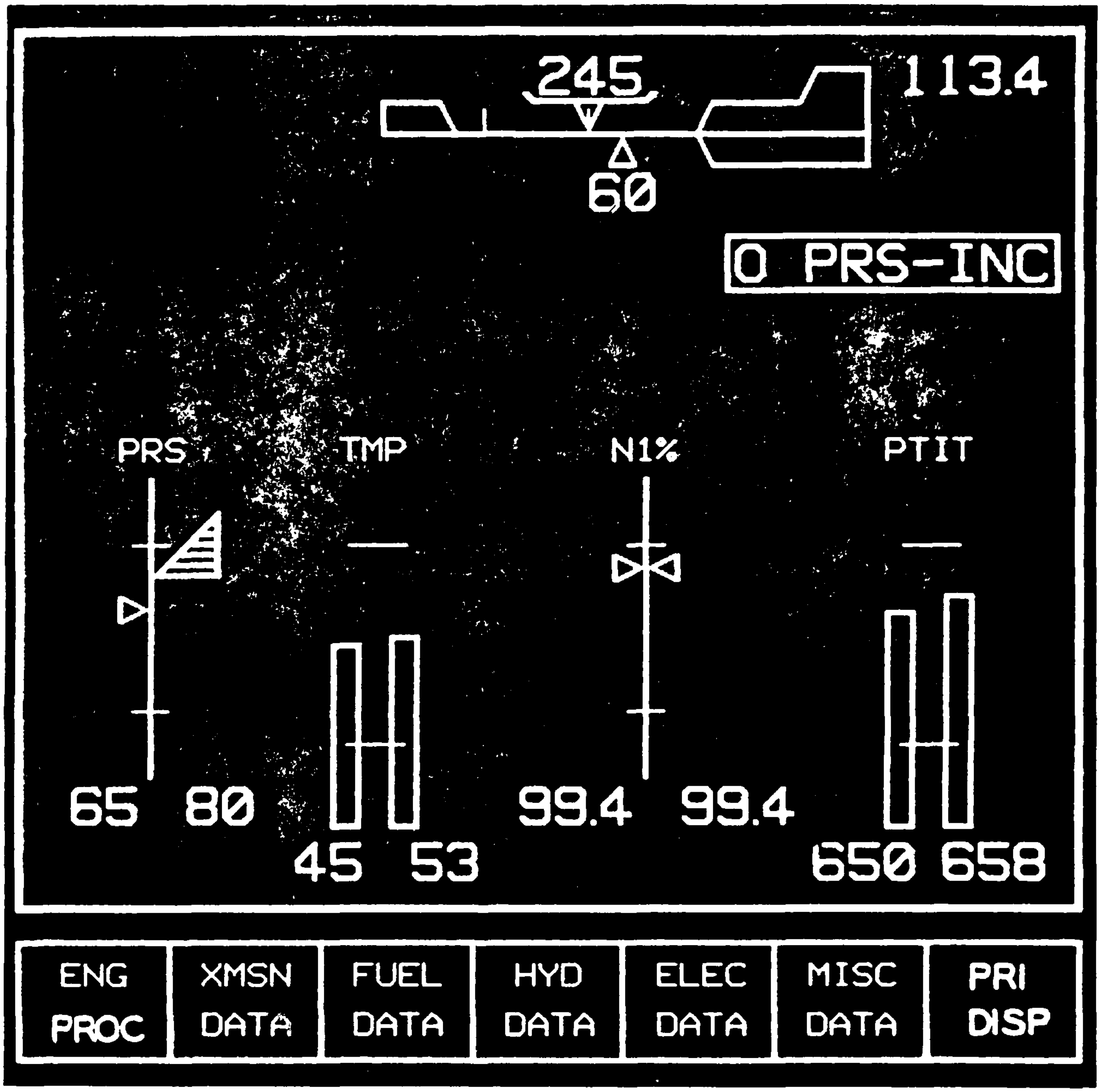
FIGURE 32




FAULTED ENGINE DISPLAY

HIGH POWER TURBINE INLET TEMPERATURE IS INDICATED BY MESSAGE CAPSULE AND BY "OUT OF NORMAL LIMITS" SYMBOLOGY. EMERGENCY PROCEDURES FOR THIS CONDITION ARE AVAILABLE BY SELECTION OF "ENG PROC".
THE DISPLAY MAY BE CLEARED BY SELECTING "PRI DISP" OR VIA THE ACKNOWLEDGE SWITCH.

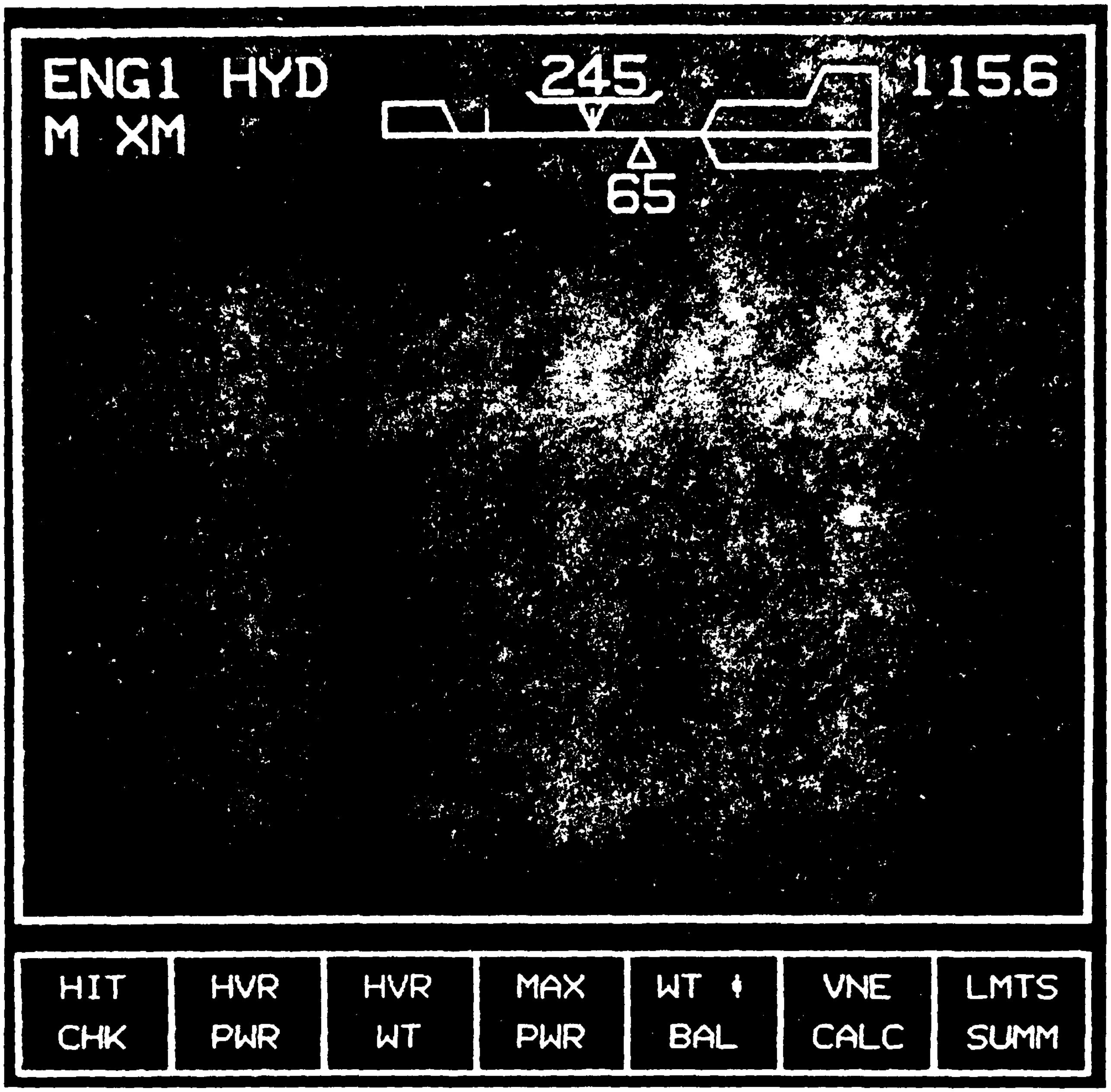
FIGURE [illegible]




TREND ENGINE DISPLAY

ENGINE OIL PRESSURE IS INCREASING AT AN ABNORMAL RATE BUT HAS NOT EXCEEDED NORMAL OPERATING LIMITS.

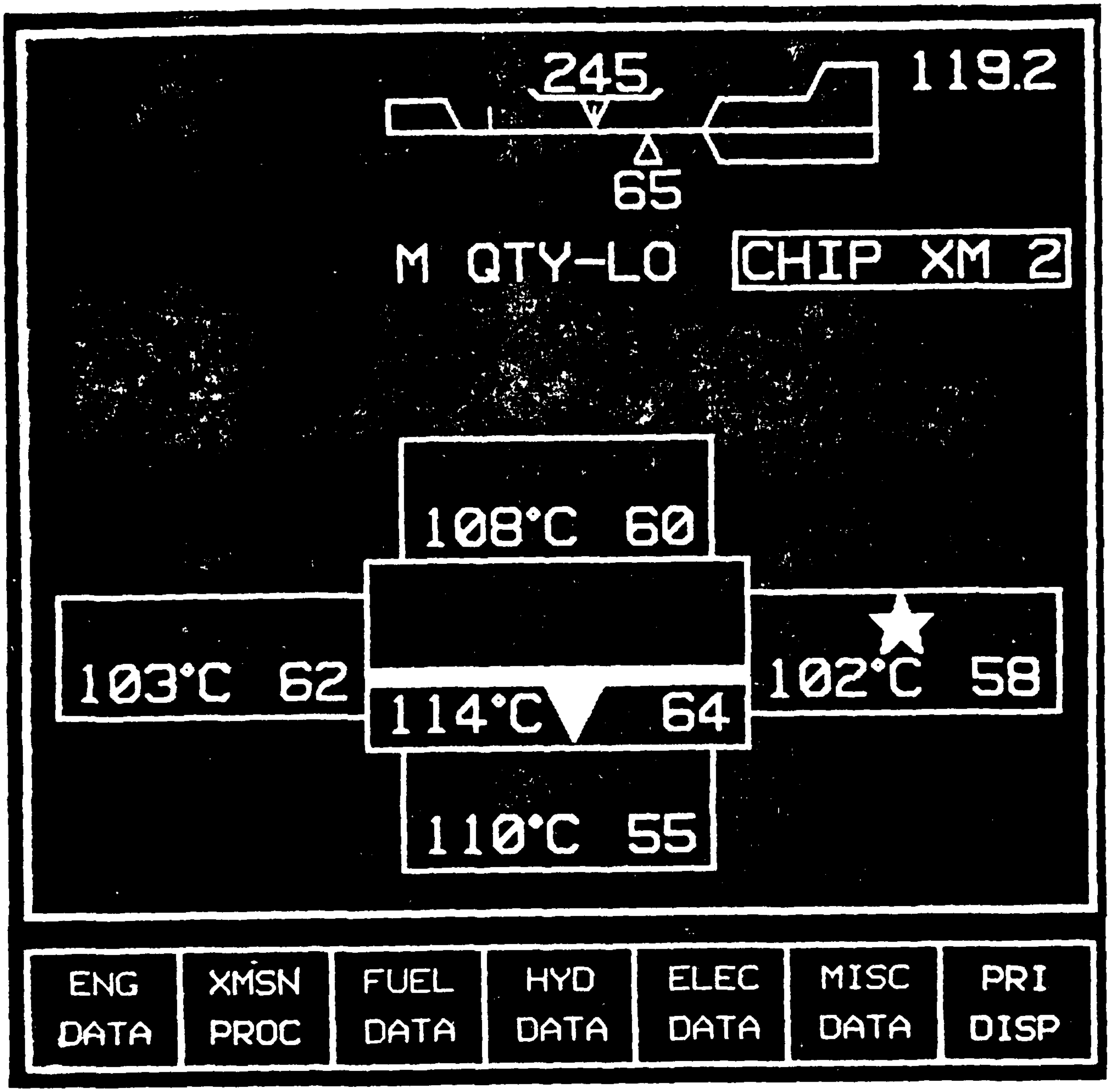
FIGURE 34




PRIMARY DISPLAY

FAULTS/WARNINGS HAVE BEEN ACKNOWLEDGED IN THE ENG, XMSN AND HYD SUB-SYSTEMS VIA NOTATION IN THE UPPER LEFT.
PERFORMANCE CALCULATION OPTIONS ARE SHOWN IN THE AVAILABLE SWITCH LEGENDS.
A FLIGHT/POST-FLIGHT SUMMARY OF MAINTENANCE RELATED PARAMETER EXCURSIONS IS AVAILABLE WITH THE SELECTION OF "LMTS SUMM"

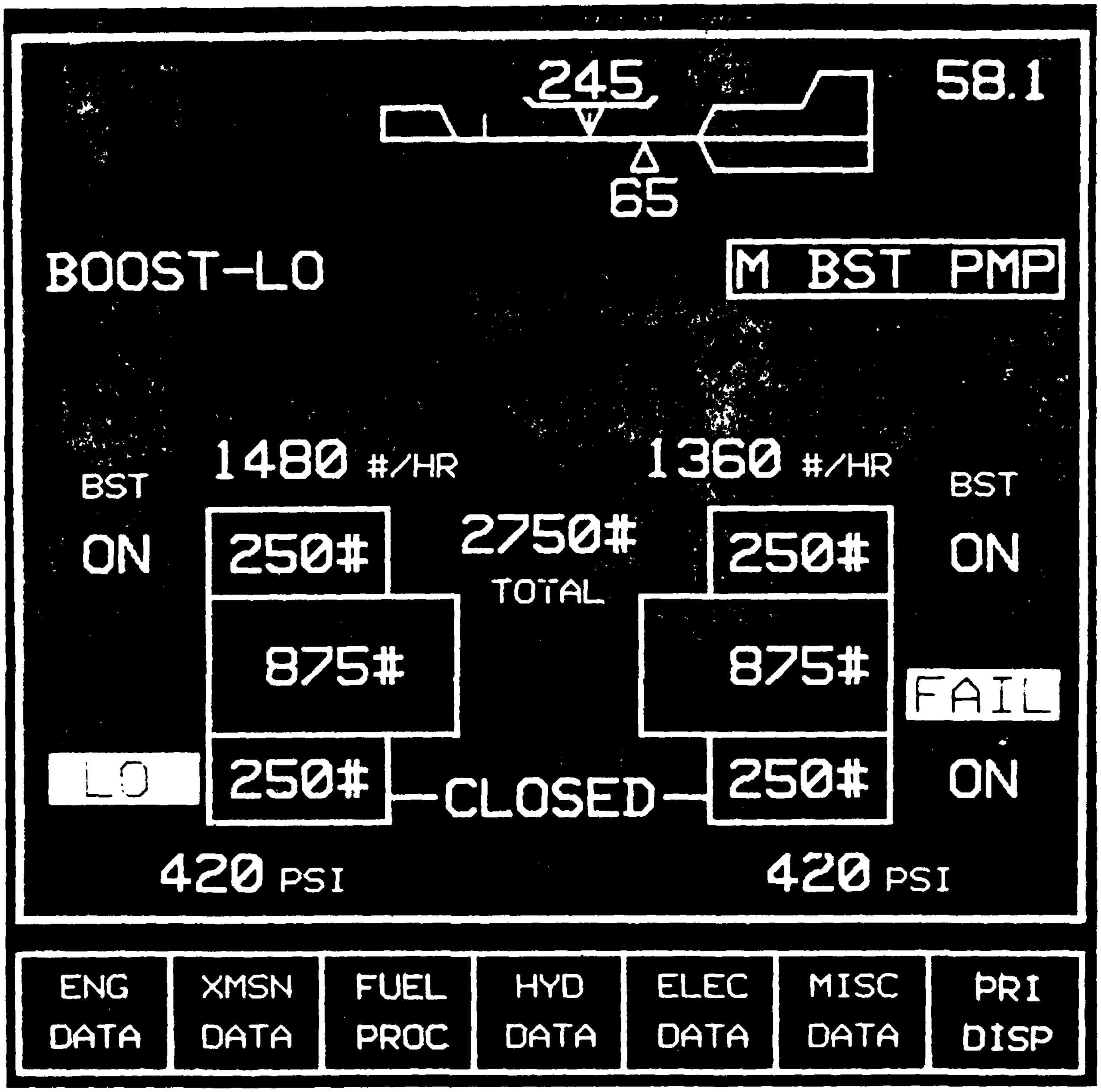
FIGURE 35




FAULTED TRANSMISSION DISPLAY

MAIN TRANSMISSION OIL QUANTITY LOW AND CHIP DETECTION IN THE ENG 2 NOSEBOX ARE INDICATED BY MESSAGE CAPSULES AND BY SCHEMATIC SYMBOLOGY.

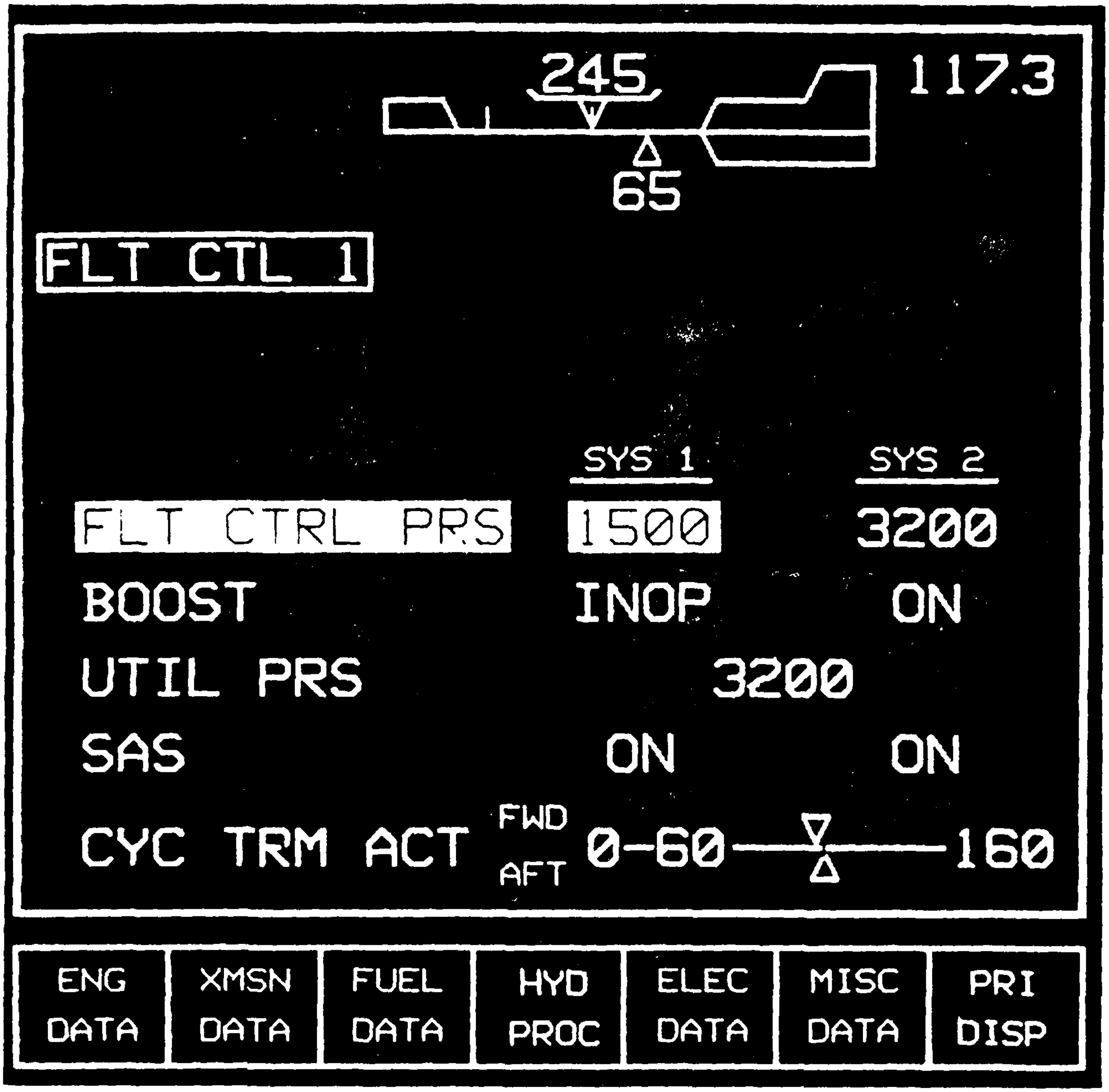
FIGURE 36




FAULTED FUEL DISPLAY

LOW BOOST PRESSURE (ENG 1-AFT AUX) AND MAIN AFT BOOST PUMP FAILURE (ENG 2) ARE INDICATED BY MESSAGE CAPSULE AND SYMBOLOGY. PROCEDURES FOR EACH CONDITION ARE AVAILABLE VIA "FUEL PROC".

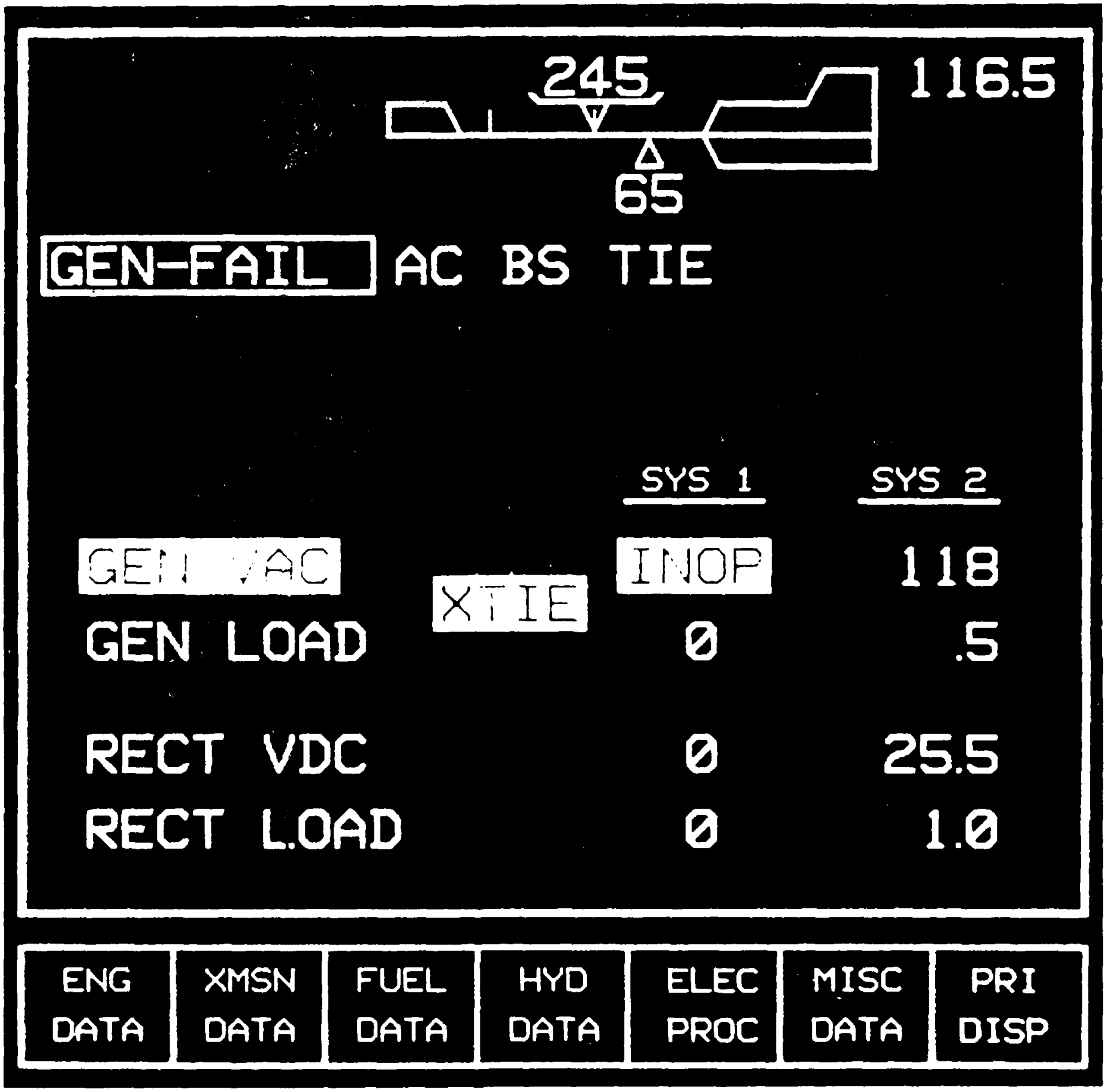
FIGURE 37




FAULTED HYDRAULIC DISPLAY

LOW FLIGHT CONTROL PRESSURE (SYS 1) IS INDICATED BY MESSAGE CAPSULE AND SYMBOLOGY. EMERGENCY PROCEDURES ARE AVAILABLE VIA "HYD PROC".

FIGURE 38




FAULTED ELECTRICAL DISPLAY

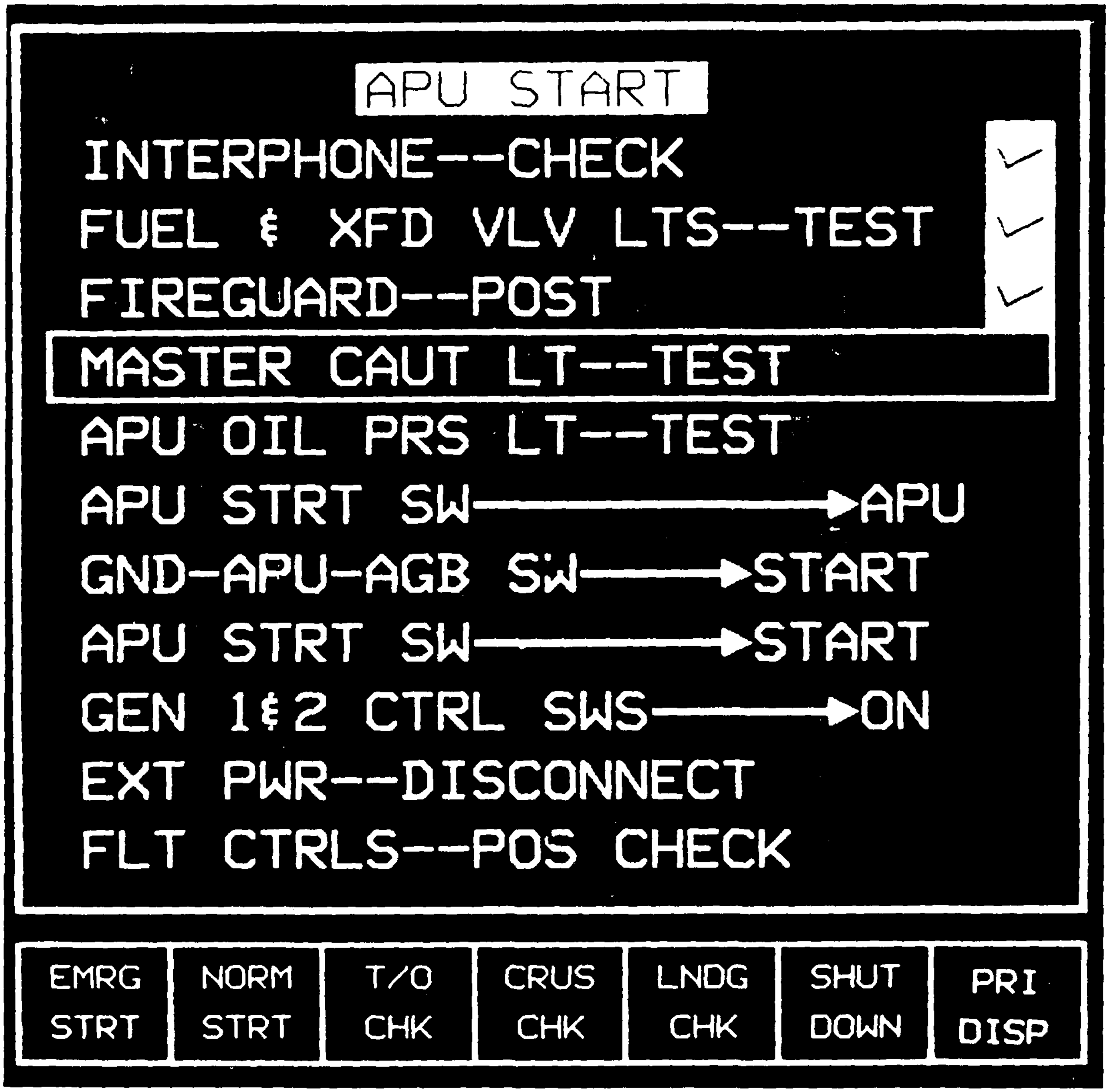
FAILED GENERATOR (SYSTEM 1) AND AN A-C BUS TIE FAILURE ARE INDICATED BY MESSAGE CAPSULE, SYMBOLOGY AND RAW DATA VALUES. EMERGENCY PROCEDURES ARE AVAILABLE VIA "ELEC PROC"

FIGURE 39


START SEQUENCE : APU

NO STEPS HAVE BEEN ACCOMPLISHED OR ACKNOWLEDGED BY THE SYSTEM. SWITCH LEGENDS SHOW AVAILABLE CHECKLIST OPTIONS AND/OR RETURN TO PRIMARY DISPLAY.

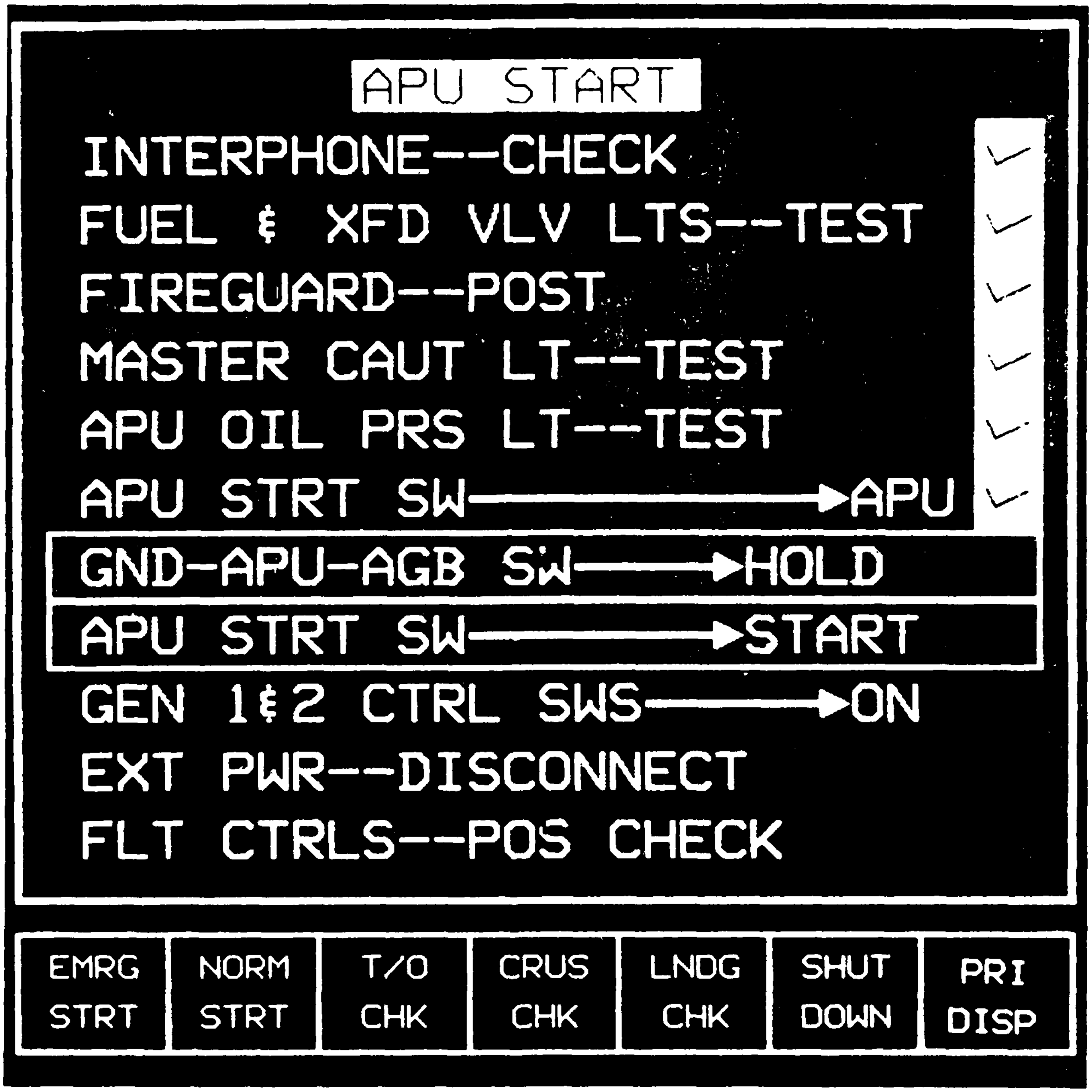
FIGURE 40




START SEQUENCE : APU

FIRST 3 STEPS HAVE BEEN ACCOMPLISHED/ACKNOWLEDGED.
ITEM 4 IS DESIGNATED AS THE NEXT STEP.

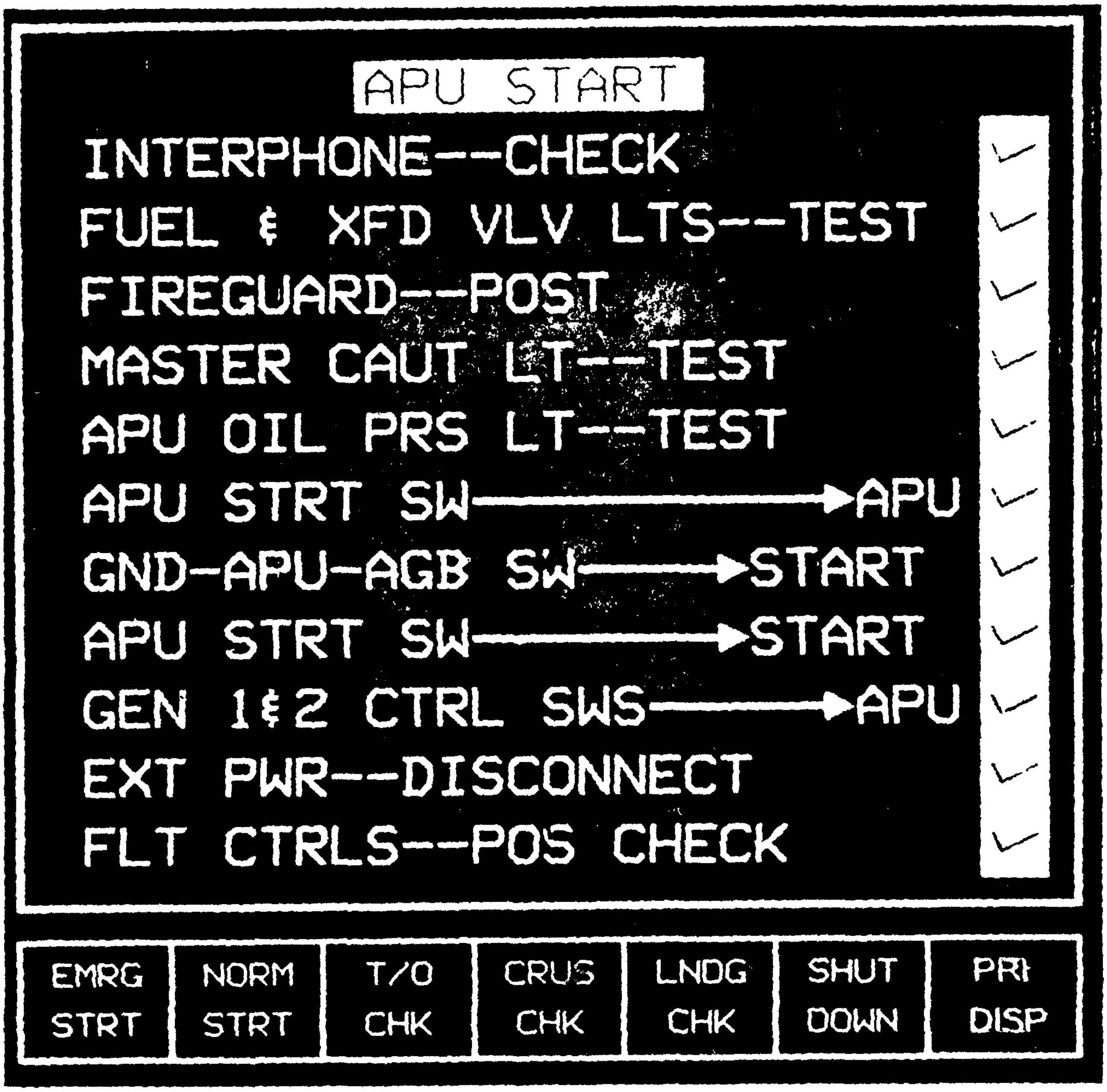
FIGURE 41




START SEQUENCE : APU

FIRST SIX ITEMS ARE ACCOMPLISHED/ACKNOWLEDGED. INSTRUCTIONS FOR STEP SIX HAVE CHANGED FROM "START" TO "HOLD" AND STEP SEVEN IS DESIGNATED AS NEXT (WHILE STEP SIX REMAINS ACTIVE).

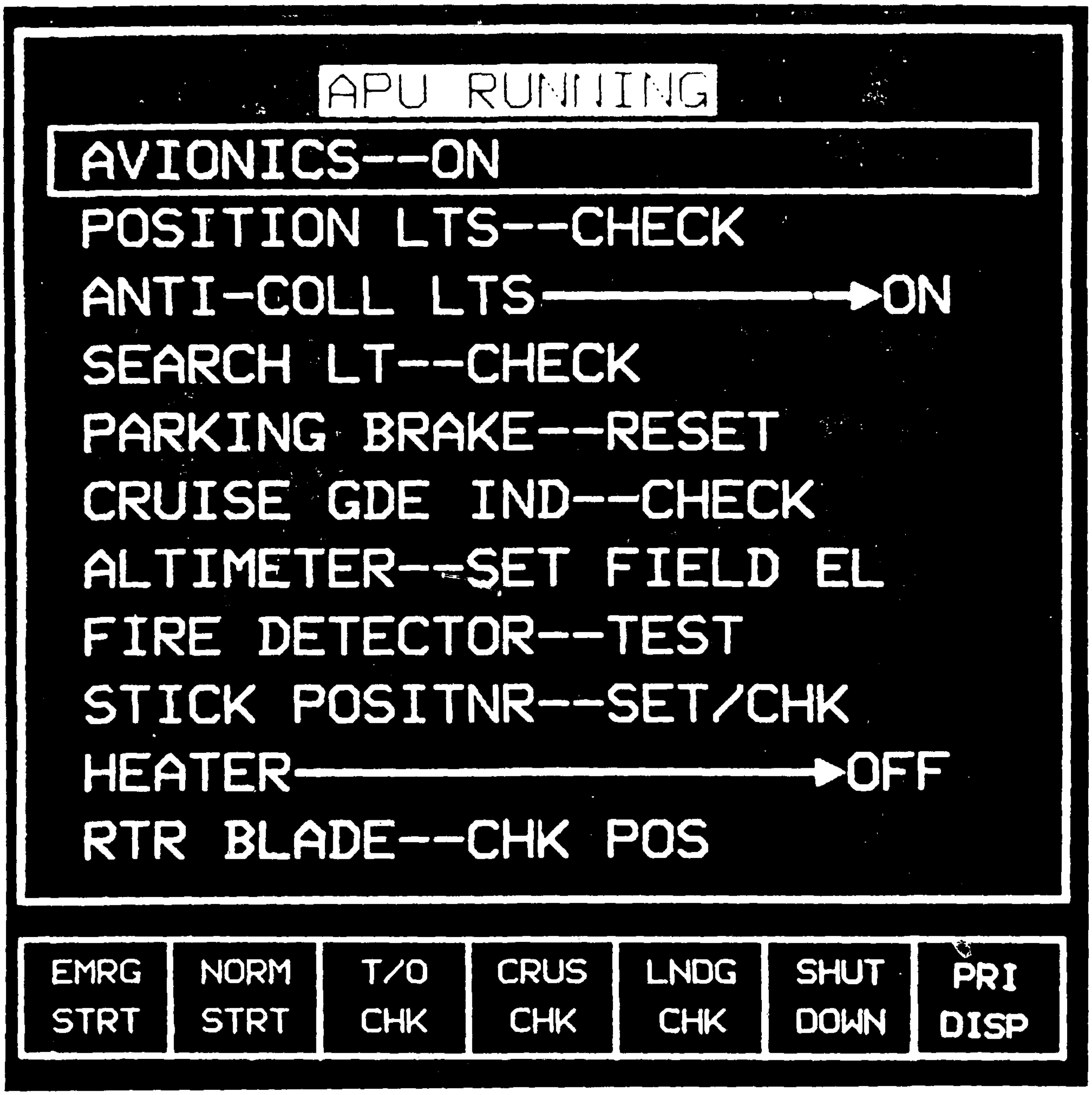
FIGURE 42




START SEQUENCE : APU

ALL ITEMS HAVE BEEN ACCOMPLISHED/ACKNOWLEDGED. THE STATUS COLUMN AT RIGHT OF PAGE IS DISPLAYED FOR VERIFICATION OF COMPLETION.

FIGURE 43



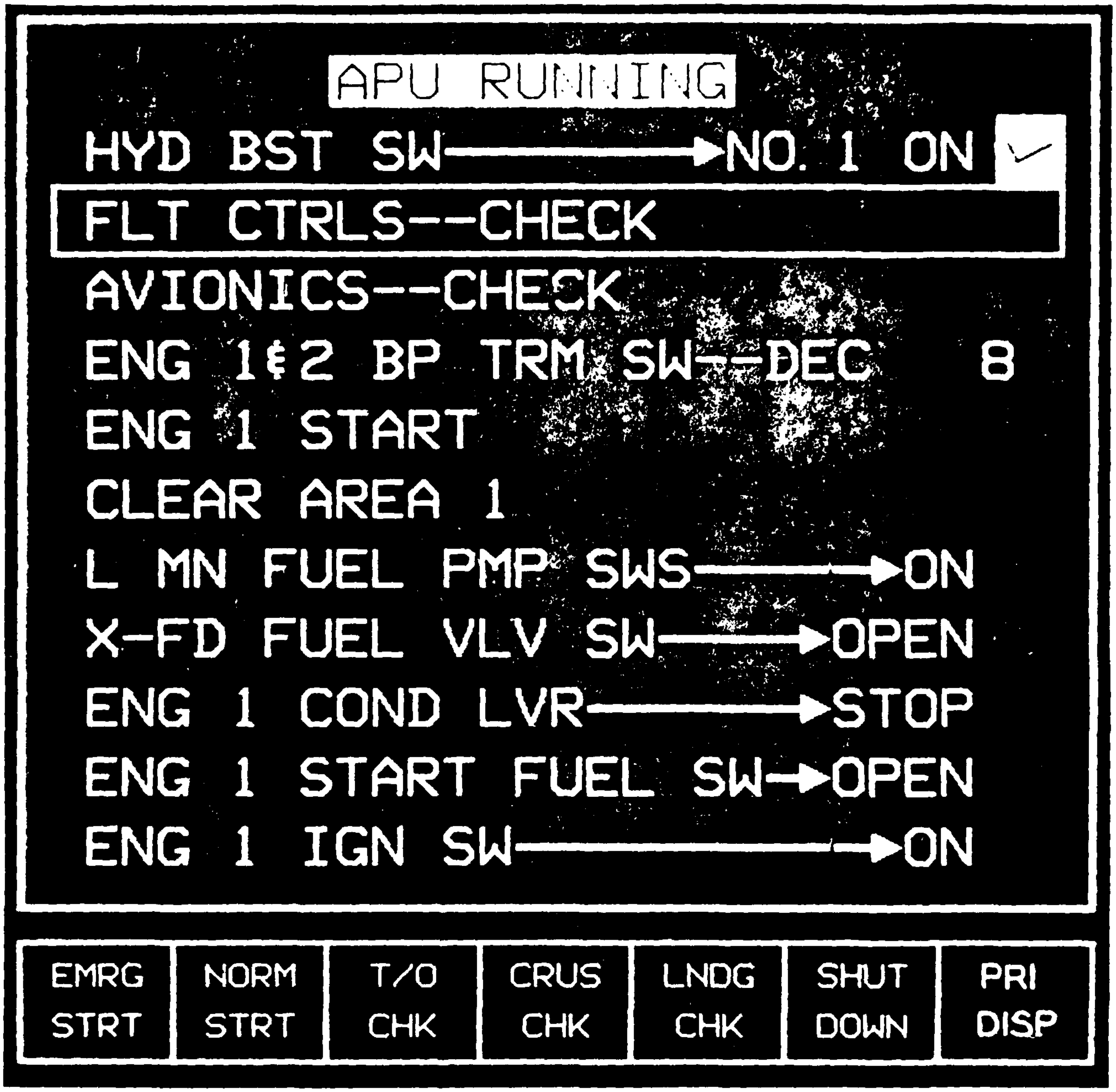

START SEQUENCE : APU RUNNING

FIRST ITEM IS DESIGNATED FOR ACCOMPLISHMENT

FIGURE 44

AD-A104 244 GENERAL ELECTRIC CO BINGHAMTON N Y AIRCRAFT EQUIPMENT DIV F/G 14/3
ELECTRONIC MASTER MONITOR AND ADVISORY DISPLAY SYSTEM, HUMAN EN--ETC(U)
JUN 81 DAAK80-79-C-0270
UNCLASSIFIED ACS-12385 AVRADCOM-TR-79-0270-3 NL

2 OF 3
AD
A104244




START SEQUENCE : APU RUNNING

AFTER COMPLETION OF ITEM 2, ITEM 1 INSTRUCTION CHANGES TO "NO. 2 ON" AND ITEM 2 REMAINS DESIGNATED FOR ACCOMPLISHMENT.

FIGURE 45

## SECTION VII. EMMADS RECOMMENDED DISPLAY/CONTROL DESIGN CRITERIA

### GENERAL

This section contains human engineering design criteria for EMMADS displays and controls. The criteria are developed from existing experimental data and design documents to maximize information transfer from the display to the human operator, and from the human operator to the controls. In this context, maximized information transfer means simultaneous satisfaction of two design goals: (1) minimum error rate by the human operator in display reading or control setting, and (2) minimum time required for display reading or control setting. Because of the time-critical nature of EMMADS-related missions, and because of the high operator workload during EMMADS-critical mission segments, both of these design goals are considered to be pertinent and key to the system performance improvement potential of EMMADS.

The following assumptions were made in developing these display/control design criteria.

- Design criteria are for the flyable version of EMMADS. While a simulator or ground-tested version is of interest, the more stringent airborne criteria are used to assure hardware compatibility with mission requirements. To this end, both vibration and ambient illumination effects are considered.
- The EMMADS display will have only upper case alphanumerics; lower case characters are unnecessary.

- Graphics will include bars, lines, and rotating lines not at 90 deg to the pixel orientation. No shading will be required; i.e., pixels will be "on" or "off."
- Ambient illuminance will vary from near zero to 10,000 foot-candles (100,000 lux in S.I. units).
- Controls will be depressable, with force feedback. Displays of control settings will be programmable, and must meet the same criteria as primary EMMADS display information.

DISPLAY DESIGN CRITERIA

To the extent possible, all design criteria are supported by empirical quantitative data. However, because interactions among design variables are known to be critical to optimal design, and because data are incomplete for some of these interactions, engineering judgment is used as necessary. In such cases, future R & D suggestions are given. Wherever possible, parametric tradeoff data supporting the recommended criteria are included.

Character Size.

In general, as the alphanumeric character size increases, legibility increases, to an asymptote. Shurtleff (1967) and Howell and Kraft (1959) have recommended that alphanumeric characters subtend at least 12 arcmin to be accurately read 85% of the time. In a more recent study (Snyder and Taylor, 1979), improvement in legibility was found to reach asymptote at 10.8 arcmin (4.79 mm at a viewing distance of 1.5 m). Thus, single alphanumeric characters should subtend a minimum of 11 arcmin to assure optimum legibility under vibration-free, adequate contrast conditions.

If the contrast is reduced by display device limitations or by ambient illuminance, then increases in character size can be traded off against reductions in contrast, as will be noted below.

In a helicopter environment, in which both the display and the operator's eyes may be vibrating, often in different amplitude/frequency combinations and out of phase, legibility will be decreased below that obtained under static conditions. In general, the stationary eye can follow a target vibrating at a frequency below 1 Hz. The degree of blurring will depend on the differences in amplitude, phase, and direction of the vibrations of the eye and the display.

The effect of vibration on the operator is complex, and depends on several parameters. First, the vibration of the head varies with vibration frequency, as shown in Figure 46. There is amplification of the vertical vibration spectrum at frequencies between 2 and 6 Hz, such that the head movement is greater than that applied to the operator's seat. Below 2 and above 6 Hz, there is some body damping. The eyeball and lens also have their own resonant frequencies, but these data are not known at this time. Fore-and-aft vibration applied to the seat also amplifies head vibration between approximately 1.5 and 2.5 Hz, with higher and lower frequencies causing some damping effect (Poulton, 1970). At frequencies above 5 Hz, the head vibrates more vertically than it does horizontally (Goldman and von Gierke, 1960).

Application of these known vibration measures to display design is not straightforward. As shown in Figure 47, larger characters are blurred less by a given amplitude vibration than are smaller characters. Assuming that the relative vibration amplitude (between observer's head and the display) can be measured, then a possible rule of thumb would be to design character heights to be increased by at least five times the differential (peak-to-peak) vibration amplitude to minimize legibility loss. This differential vibration calculation, of course, would take into account the vibration frequencies, as shown in Figure 46.

A few simulation studies have indicated no visual impairment in the vertical axis up to levels of 0.4 RMS $g_z$, with the worst acuity decrement between 4 and 7 Hz (Pradko, 1964). At best, the existing data are inconsistent (Hornick, 1973).

In summary, high contrast alphanumerics should be maximally legible at an angular subtense of at least 11 arcmin, and increases in size will most likely be required to obtain the same performance levels under vibration conditions. The influence of a representative vibration spectra on character size and cell attributes will be quantitatively discussed later in this section.

Matrix size

Manufacturers are generally consistent in the dimensions of the dot-matrix characters they utilize. Most commercially available displays use characters which are 5 dots wide and 7 dots high.

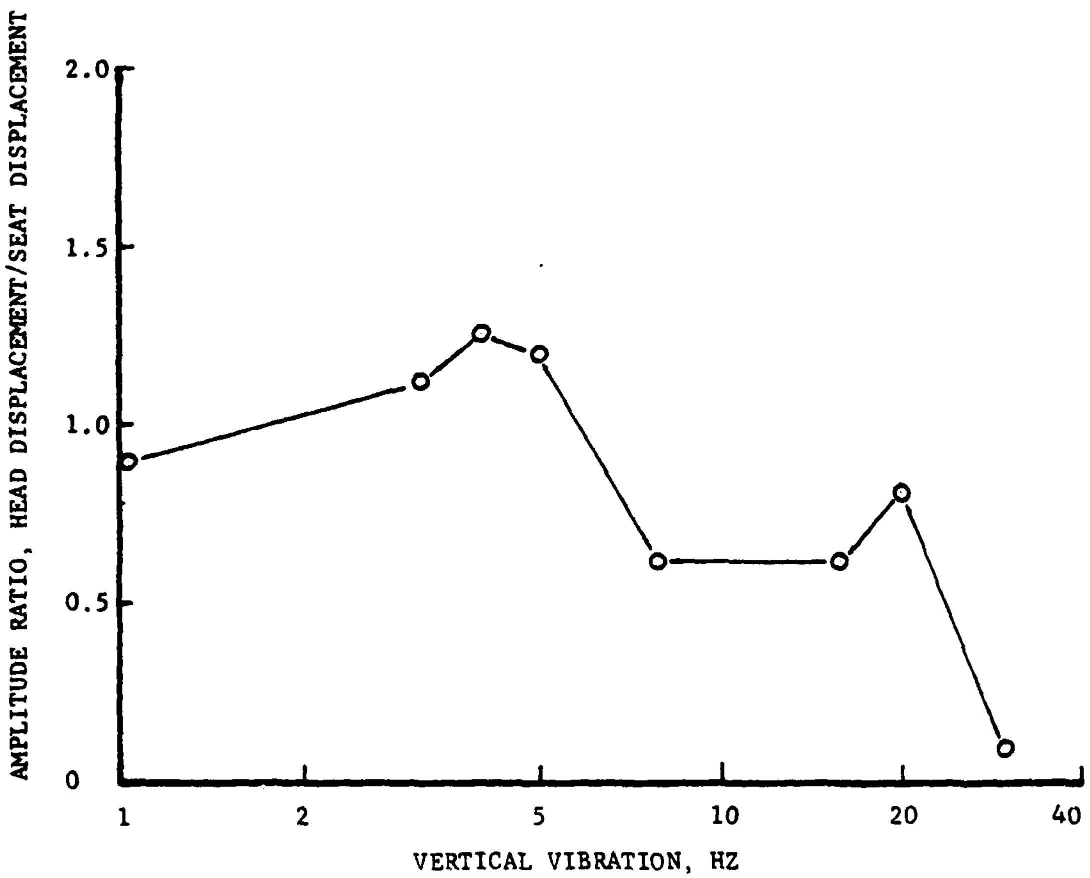



FIGURE 46. EFFECT OF VIBRATION FREQUENCY UPON HEAD VIBRATION AMPLITUDE.
From Poulton (1970), p. 212

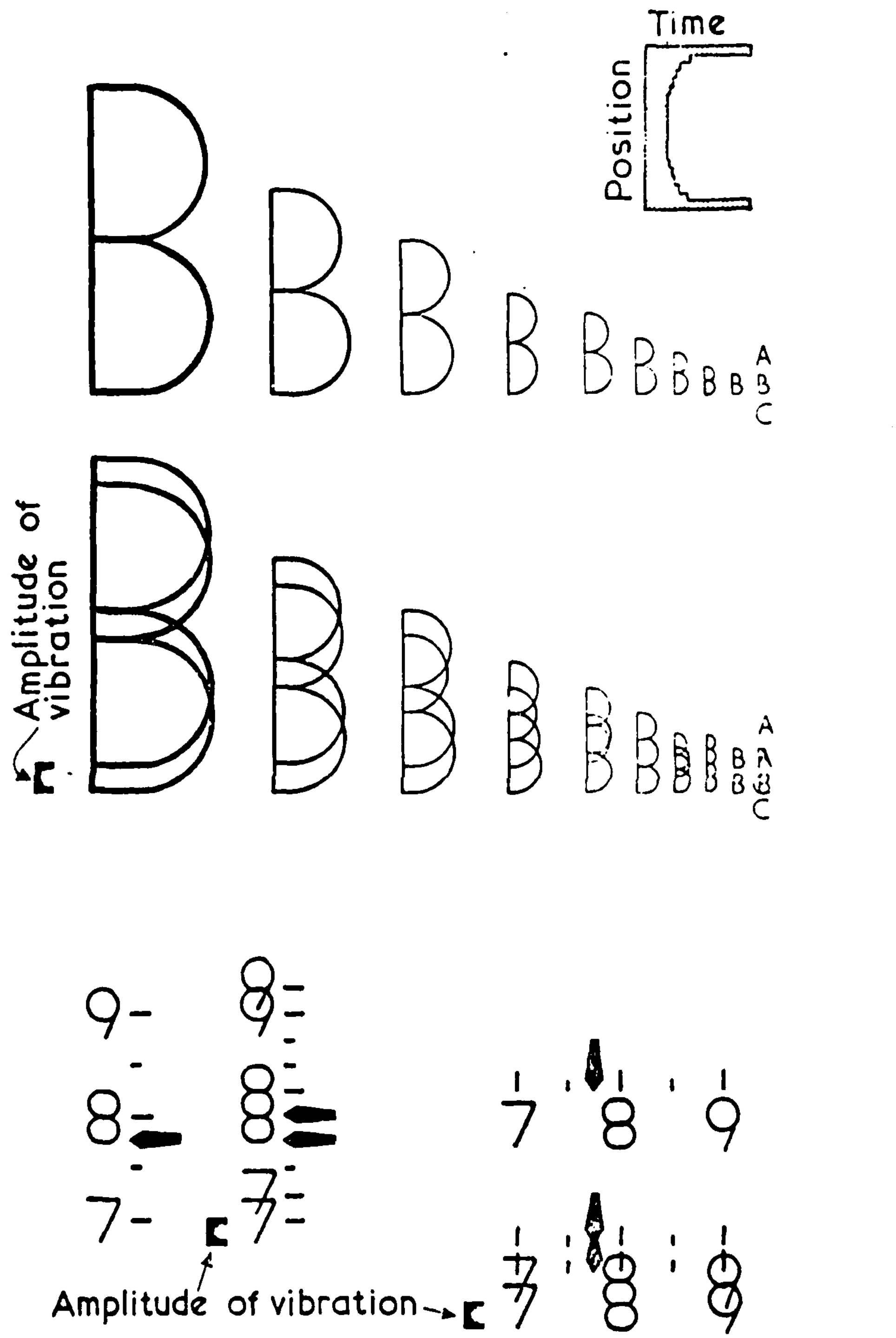



Figure 47. Graphical illustration of perceived blur during vertical vibration.

A smaller number of displays, particularly those requiring both upper- and lower-case letters, use 7 x 9 or 9 x 11 characters. The number of dots available for making up characters is generally referred to as the matrix size.

Experimental work in this area has demonstrated that the larger the matrix size the more legible the character, on the average. However, larger matrix sizes yield smaller improvements beyond 7 x 9 or 9 x 11. Thus, while it is possible to demonstrate a measureable improvement in legibility with, say, an 11 x 16 matrix over a 7 x 9, the costs associated with the larger 176-element matrix, compared with the 63-element matrix, makes the selection of the larger matrix typically inappropriate.

One must be cautious in evaluating the existing experimental data on matrix size effects. Two meaningful approaches can be, and have been, taken. First, one can assume a dot size which is fixed by hardware constraints, such that increases in matrix size are accompanied by proportional increases in character size. In this case, only software changes are typically needed to effect matrix size changes. The alternative or second choice is to assume that dot sizes can be altered in hardware, such that both hardware and software changes are needed to vary matrix size. In this case, matrix size can be varied independently of character size.

The importance of this distinction is illustrated in Figure 48, which shows the results of the only experiment which has separated the effects of these variables. As indicated, the 9 x 11 is superior to the 7 x 9, which, in turn, is superior to the 5 x 7 for all upper-case, singularly-presented alphanumerics.

The fourth column (or bar) shows performance for a 7 x 9 matrix equal in size to the 5 x 7 matrix, while the fifth column pertains to a 9 x 11 matrix equal in size to the 5 x 7.

Thus, the larger the matrix size, the fewer the reading errors. Moreover, the large matrix size, accompanied by reductions in character size, the fewer the errors. Performance with the 9 x 11 (= 5 x 7) size was superior to the other four conditions ($p < .01$). This is most likely due to the proportionately reduced space between dots, which causes the smaller character size with more dots to resemble more closely a stroke character (Snyder and Maddox, 1978).

Reading from left to right in Figure 48, the vertical angular subtenses of the five sizes are: 48.5, 63.0, 77.2, 48.5, and 48.5 arcminutes. It seems reasonable to assume that the same relative results would have been obtained for smaller character sizes, such as the 11 arcminutes recommended above.

In summary, a 9 x 11 matrix size will produce approximately 23% fewer errors than will a 7 x 9 matrix size. The 7 x 9 matrix size will, in turn, produce approximately 31% fewer errors than will the 5 x 7, even when font selection is reasonably optimal (Snyder and Maddox, 1978). For these reasons, the recommended all upper case dot matrix characters should have a 9 x 11 matrix size and subtend at lease 11 arcminutes. However, if hardware or software constraints preclude a 9 x 11 matrix, then no smaller than a 7 x 9 matrix should be used, with the awareness that legibility may be significantly decreased.

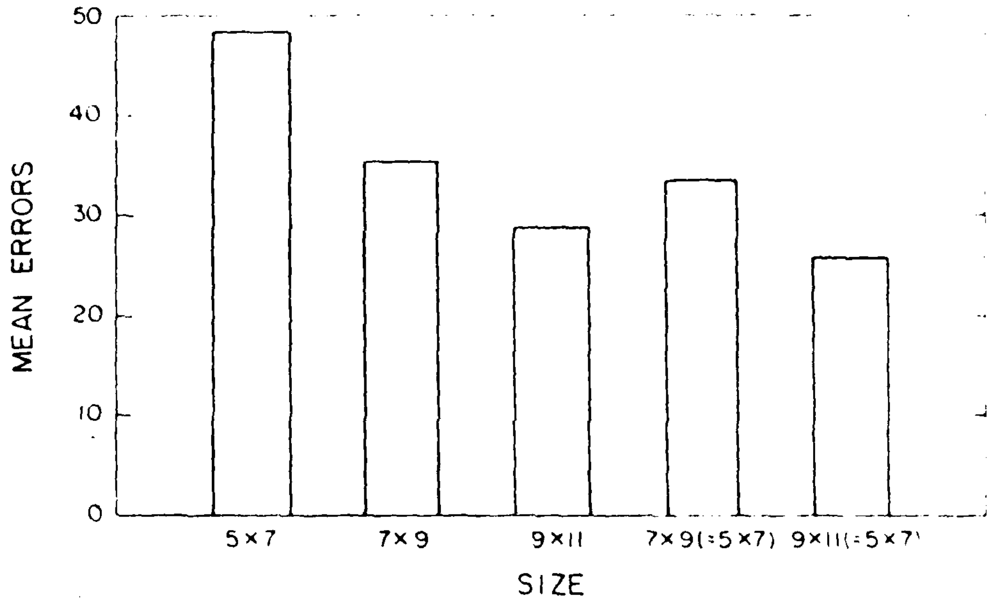



**Figure 48.** Effect of Character/Matrix Size upon Number of Errors

## Character Font

It has been recognized for some time that certain characteristics of stroke alphanumerics affect their relative legibility. These characteristics have been gathered under the term "font". Much research has been undertaken to ascertain which stroke font is the most legible under certain conditions (cf. Cornog and Rose, 1967). Some of the more familiar stroke fonts are the Leroy, BUIC, Mackworth, and the Lincoln/Mitre. It was not satisfactorily demonstrated in previous studies that the conclusions from stroke font research are directly transferrable to dot-matrix fonts, although two studies indicated that the Lincoln/Mitre font, adapted to dot-matrix constraints, is superior to other commonly used fonts (Shurtleff, 1970; VanderKolk, Herman, and Hershberger, 1974).

The fonts developed for use by commercial manufacturers of dot-matrix display devices are, for the most part, not based on the meager body of knowledge on the subject. Indeed, most commercially available dot-matrix fonts seem to be based more on expediency than on any desire to standardize or to maximize legibility.

Because stroke fonts do not directly adapt to dot matrix geometric constraints, one cannot use this earlier stroke font experimental data, and must rely instead on data generated specifically to compare dot-matrix fonts. Only two such studies have been reported in a complete-alphabet evaluation. These studies compared a dot matrix adaptation of the accepted Lincoln/Mitre font, the Huddleston font (developed specifically for the high ambient aircraft environment), and two additional, newly designed fonts, designated the "maximum dot" and "maximum angle" fonts (Snyder and Maddox, 1978).

While the overall results of the experiment demonstrated that the Huddleston and Lincoln/Mitre fonts were superior to the other two, it is apparent that font selection should be made in conjunction with the selection of character/matrix size, as illustrated in Figure 49.

For the 7 x 9 font, the Lincoln/Mitre was found to be superior to the other three ($p < .05$), and for the 7 x 9 (= 5 x 7), the Lincoln/Mitre and Huddleston are statistically nondifferent.

For the 9 x 11, the Lincoln/Mitre was found to be superior to the Huddleston ($p < .05$), while they are statistically nondifferent for the 9 x 11 (= 5 x 7) size.

Thus, for either 7 x 9 or 9 x 11 matrix sizes, the Lincoln/Mitre font is recommended. This font is illustrated in Figures 50 and 51.

## Dot Size, Shape, and Spacing

### Dot size and spacing

It has been demonstrated that the size and shape of the illuminated display dots can significantly affect both single character search time and reading speed. It is quite likely that single character legibility would be similarly affected (Snyder and Taylor, 1979).

The influence of dot size upon operator performance is indirectly the result of the spacing between dots (Snyder and Maddox, 1978). As the inter-dot spacing increases, performance decreases (Figure 52). Thus, the ratio of inter-dot space to dot size should be as small as possible, and certainly less than 0.5.

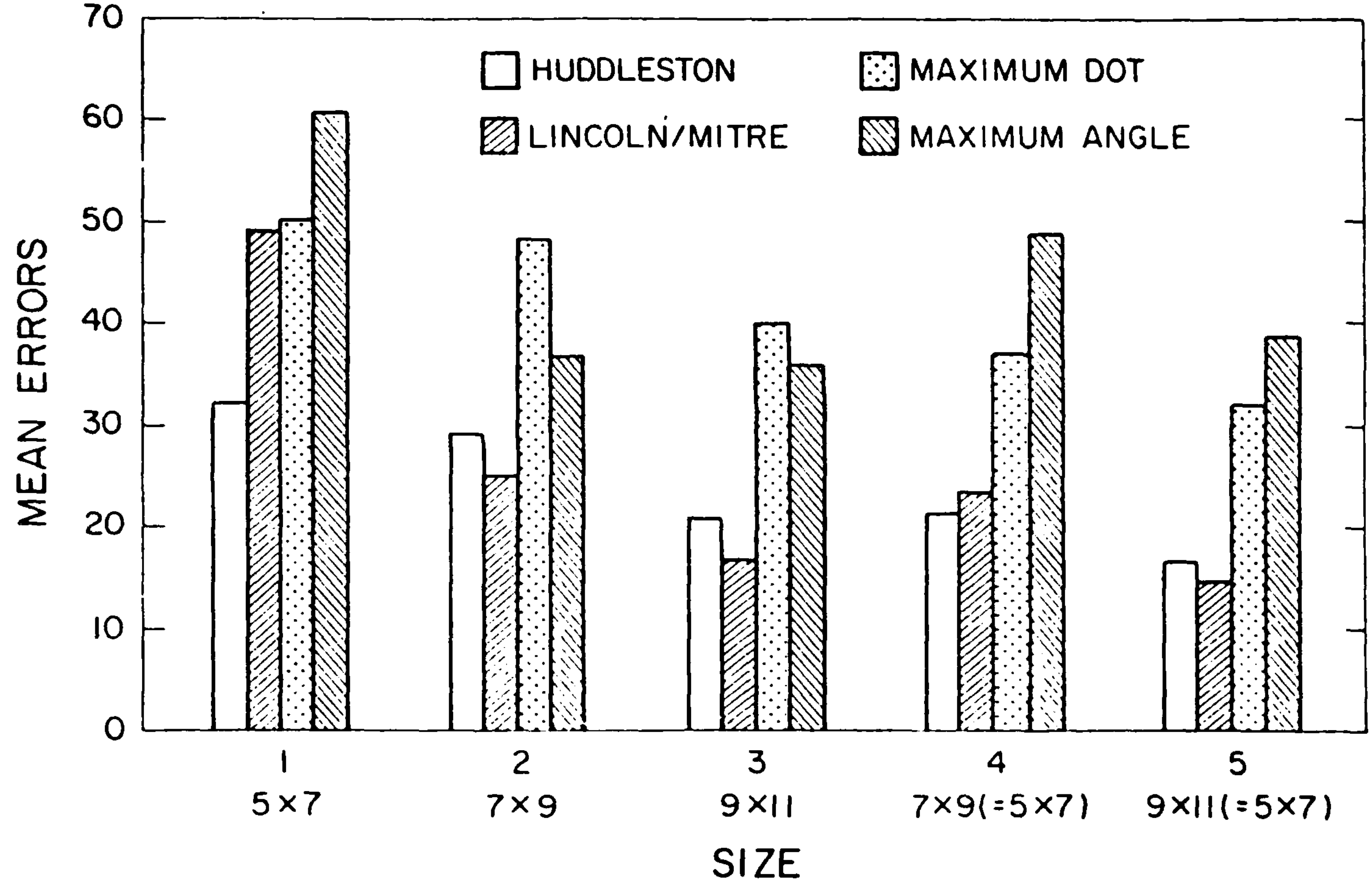



Figure 49. Effect of Character/Matrix Size by Font Interaction upon Number of Errors

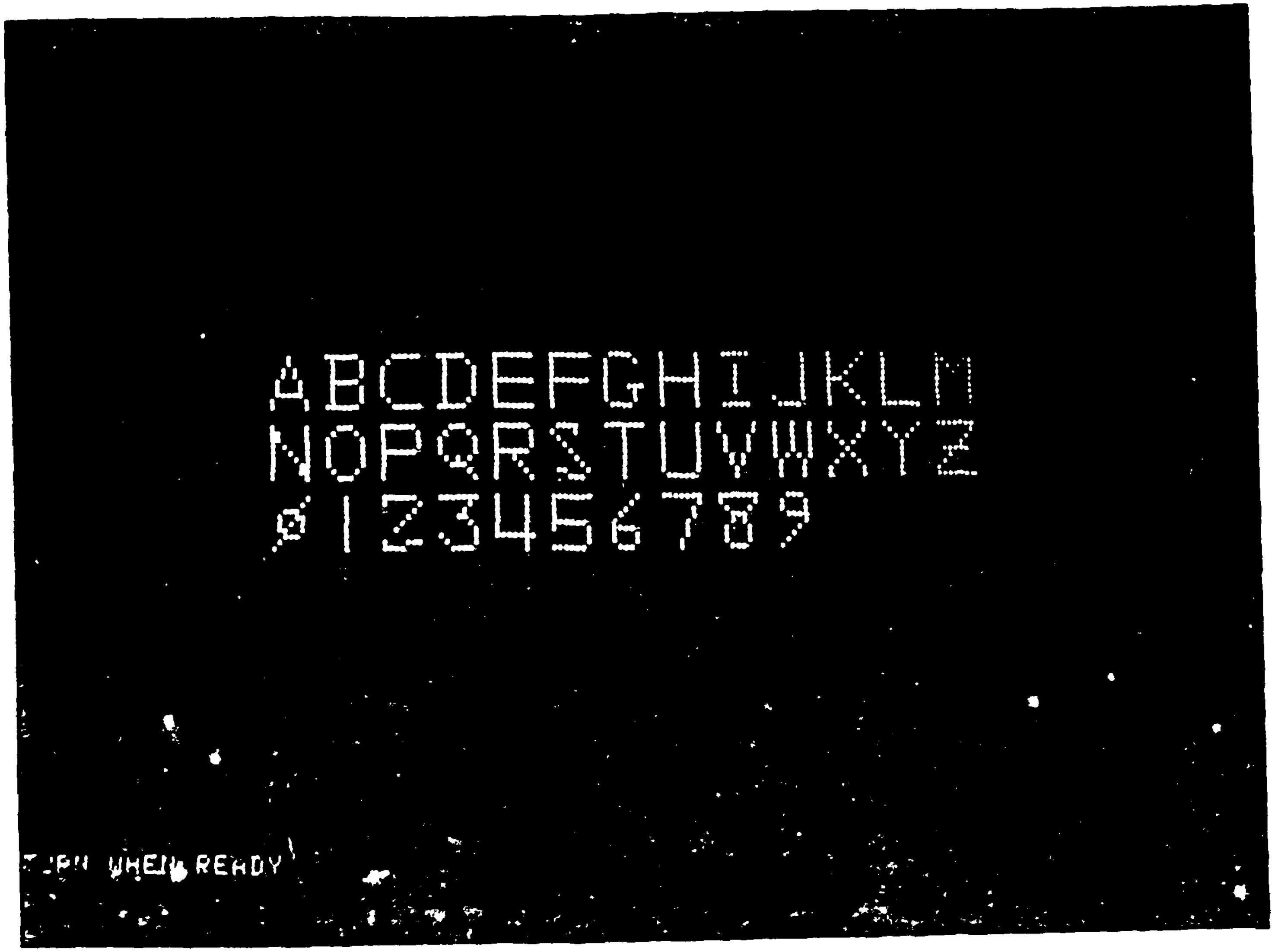



Figure 50. Lincoln/Mitre Font in 7 × 9 (5 × 7 Size) Matrix


Figure 51. Lincoln/Mitre Font in 9 × 11 Matrix

Assuming a 9 x 11 matrix size with an angular subtense of 11 arcminutes, the inter-dot spacing should be less than 0.34 arcminutes. Even for very acute vision, this spacing will be imperceptible. (At a panel distance of 72 cm, this inter-dot space on a 9 x 11 character would be 0.41 mm, and the dot size would be 0.82 mm).

As suggested by the dotted line in Figure 52, smaller relative spaces between dots will lead to additional increases in performance, until the dot matrix character essentially becomes a stroke character (ratio of inter-dot space to dot size equals zero).

Dot shape

The more nearly square the dot shape, the better the search and reading performance (Figure 53), especially under high ambient illuminance (Figure 54). In addition, a mathematical Fourier-based prediction model also substantiates the need for individual dots to approximate a square shape which, in turn, makes spaces between dots less noticeable (for the same dot maximum dimension).

Thus, the recommended 9 x 11 matrix should have square dots, with a maximum inter-dot spacing of 0.5 arcminute. Should a 7 x 9 matrix be used, the same maximum 0.5 arcminute spacing should be used, based upon known visual acuity limits.

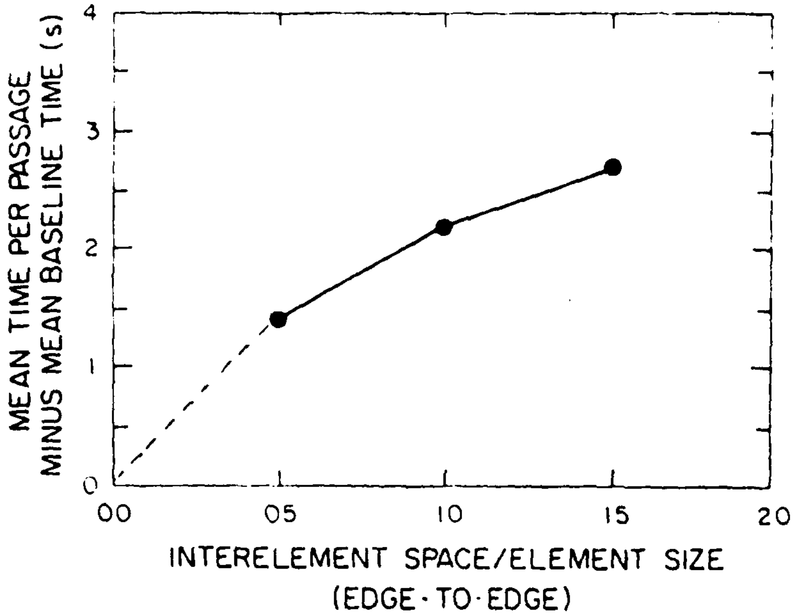



Figure 52. Effect of Interelement Spacing Ratio upon Reading Time

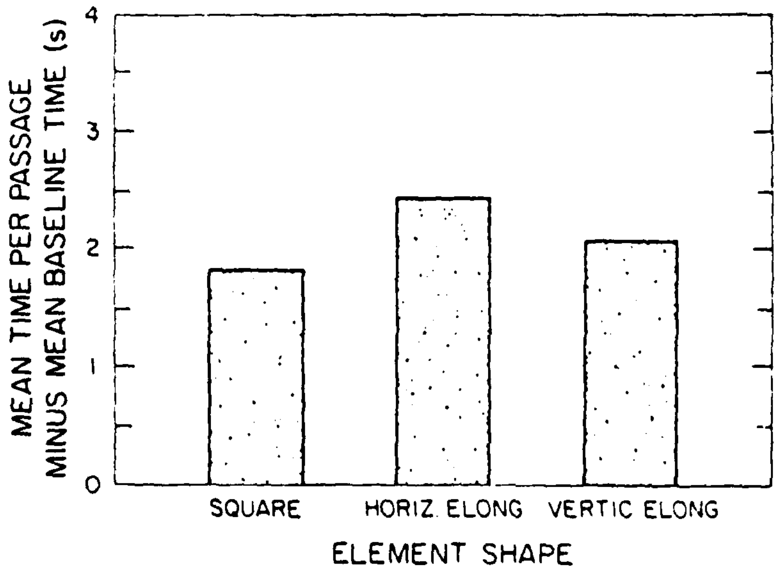



Figure 53. Effect of Element Shape on Reading Time

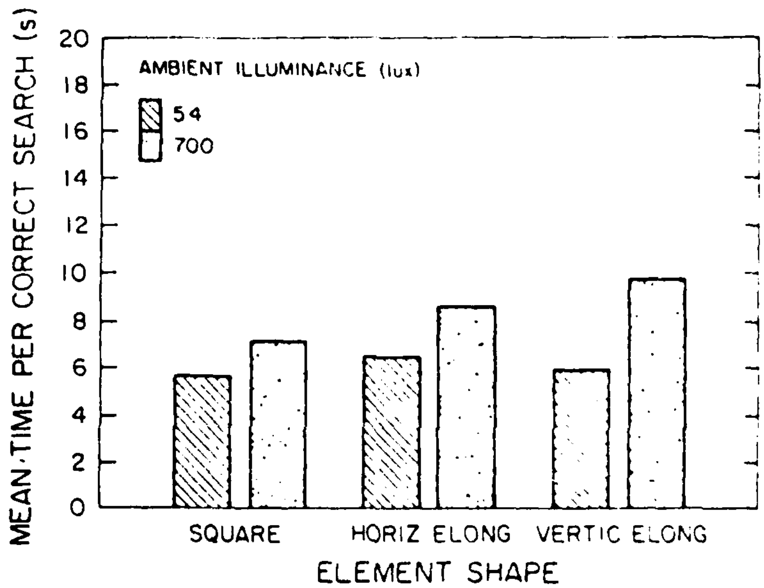



Figure 54. Effect of Element Shape by Illuminance Interaction upon Random Search Time

VIBRATION SPECTRA

As a representative descrption of a "Design" vibration environment, the data supplied by Hutchins (1972) for the CH-47C and SH-3A helicopters will be used. The vibration spectra data will be used to modify the above design criteria to establish character and cell criteria for the Flight-Test version of EMMADS.

Hutchins (1972) measured triaxial vibrations at various places in the cockpit of the CH-47C and SH-3A helicopters during several mission segments. Of importance to EMMADS are the vibration spectra at the instrument panel and at the head of the pilot. While seat displacement was also measured, the body significantly dampens the vertical (z-axis) motion, and therefore is less relevant than head motion. Hutchins measured head motion from an accelerometer mounted on a dental bite bar. Table 7 contains the relevant data from Hutchins's report.

The frequency bands for the two helicopters are slightly different because of the blade rotation frequency, which occurs at the lower frequency band. Unfortunately, Hutchins gives no data on the phase relationships among the several measured locations.

TABLE 7. RMS $G_z$ levels, from Hutchins (1972)

| Helicopter | Location | Frequency 3.4 Hz | 6.8 Hz | 17 Hz |
|---|---|---|---|---|
| SH-3A | Instrument Panel | 0.022 | 0.045 | 0.063 |
| | Bite Bar | 0.034 | 0.011 | 0.020 |
| | Pilot Seat | 0.026 | 0.012 | 0.100 |
| | | 3.9 Hz | 12 Hz | 24 Hz |
| CH-47C | Instrument Panel | 0.031 | 0.063 | 0.320 |
| | Bite Bar | 0.062 | 0.022 | 0.018 |
| | Pilot Seat | 0.020 | 0.045 | 0.100 |

The tabled RMS G values can be converted into amplitude values by the equation:

$$g = 0.0511 \text{ (p-p amplitude) } (f^2)$$

or

$$\text{peak-peak amplitude} = 19.569 \, g \, f^{-2}$$

Evaluating the values of Table 7 leads to the determination that the greatest peak-to-peak amplitude occurs at 3.9 Hz at the pilot's head. For this case, the acceleration of 0.062 RMC $G_z$ yields a peak-to-peak amplitude of 2.026 mm. This value was used as the "worst case" condition for design purposes.

Design Criteria Modification

If the characters to be presented on EMMADS are all upper case letters or numerals in 7 x 9 dot matrix Lincoln-Mitre font, then the closest horizontal elements which can cause a "confusion" or misreading are the

horizontal "lines" of the letter E. These "lines" are separated by three dots; i.e., the top and middle (or middle and bottom) lines have three dots or potential lines between them, as shown in Figure 55.

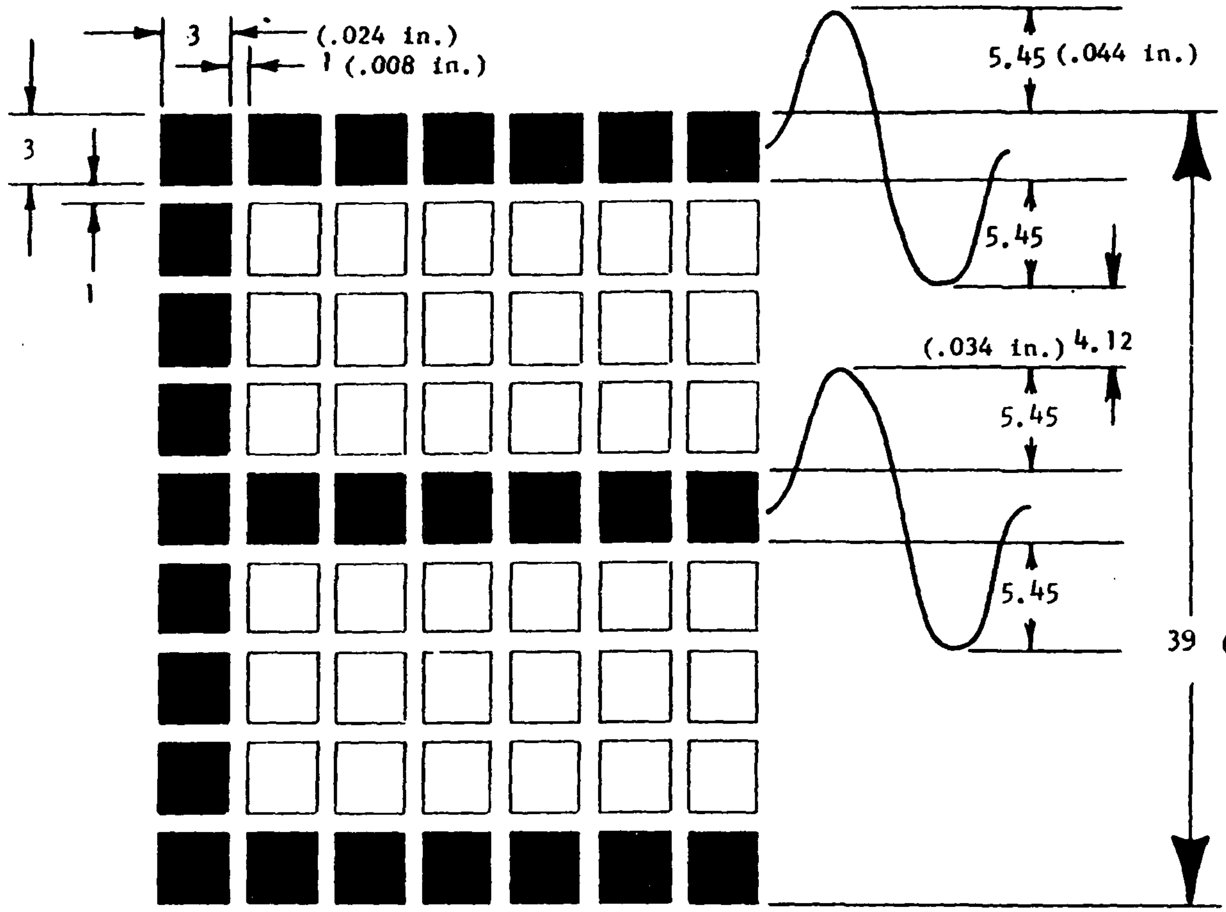
A safe design approach is to assure the non-overlap of the vibrated letter under the worst vibration condition. That is, as the pilot's head and the instrument panel are vibrated vertically, the displacement of the horizontal lines of the displayed letter E must not overlap. The spacing between the horizontal lines on the display is set to avoid this overlap in displacement, as follows.

First, the combined pilot's head and instrument panel vertical displacements are taken as the root sum square of the two separate displacements for the critical vibration conditions. This RSS $G_z$ is 0.069, yielding an equivalent vertical peak-to-peak displacement of 2.261 mm.

Second, we assume the panel distance to be 71.12 cm (28 in.) to calculate the angular equivalent of this displacement, which is 10.90 arcminutes peak-to-peak. The half-amplitude, 5.45 arcmin, is illustrated in Figure 55, as the displacement in either direction (up or down) of the horizontal lines of the character. (It is convenient to think of the pilot's head being fixed and the panel moving, although the true movement is actually the relative movement between the two.)

Third, the angular separation between the edges of the horizontal "lines" must be at least 4.12 arcmin to achieve optimum single character recognition under vibration free conditions. Three cells plus 4 spaces subtend 4.12 arcmin. Thus, the maximally vibrated lines must be not closer than 4.12 arcmin.

FIGURE 55. CHARACTER LEGIBILITY CRITERIA* FOR CH-47 VIBRATION




* minutes of arc (Inches for 28 in. viewing distance)

Fourth, the center-to-center separation between the horizontal lines of the E should be at least 5.45 + 5.45 + 4.12 = 15.02 arcmin. The dot-width/dot-spacing ratio should remain at least 2:1 even though the character size is increased. And the space should not exceed 1 arcmin to avoid legibility reduction during vibration-free conditions.

The following simultaneous equations can be solved for the dot width and dot spacing.

$$H = 9\,W + 8\,S, \tag{1}$$

$$\begin{aligned} 0.5\,H &= 0.5\,W + 5.45\text{ arcmin} + 4.12\text{ arcmin} + 5.45\text{ arcmin} + W \\ &= 1.5\,W + 15.02\text{ arcmin, and} \end{aligned} \tag{2}$$

$$S = 0.5\,W,$$

where

$H$ = character height,

$W$ = dot width, and

$S$ = space width.

Accordingly, the solution is:

$H$ = 39 arcmin,

$S$ = 1 arcmin, and

$W$ = 3 arcmin.

Modified Criteria

To maintain adequate legibility under the indicated representative vibration conditions, the following revised display criteria are suggested.

Character height: 39 arcminutes

Interdot (edge-to-edge) spacing: 1 arcmin

Dot width: 3 arcmin

## Dot Contrast

There are many definitions of contrast, and one needs to be careful in comparing sources of information. The most useful is often called modulation, M, which is defined as:

$$M = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} , \qquad (1)$$

where

$L_{max}$ = maximum luminance ("on" dot), and

$L_{min}$ = minimum luminance (space between dots).

The relationships between modulation and other "contrast" measures are as follows:

$$\text{Contrast Ratio} = \frac{L_{max}}{L_{min}} = \frac{M + 1}{1 - M} , \qquad (2)$$

$$\text{Dynamic Range} = L_{max} - L_{min} = \frac{L_{max} \cdot 2\,M}{M + 1} , \text{ and} \qquad (3)$$

$$\text{Relative Contrast} = \frac{L_{max} - L_{min}}{L_{min}} = \frac{2\,M}{1 - M}. \qquad (4)$$

Generally speaking, there are significant increases in display legibility as modulation is increased up to about 0.90 (Howell and Kraft, 1959). As illustrated in Figure 56, increases in dot luminance from 8 $cd/m^2$ (M = 0.41) to 27 $cd/m^2$ (M = 0.78) produced significant legibility increases for all character sizes; further luminance increases to 30 $cd/m^2$ (M = 0.92) did not improve legibility significantly.

As illustrated in Figure 57, increases in character size can be used to compensate for decreases in modulation.

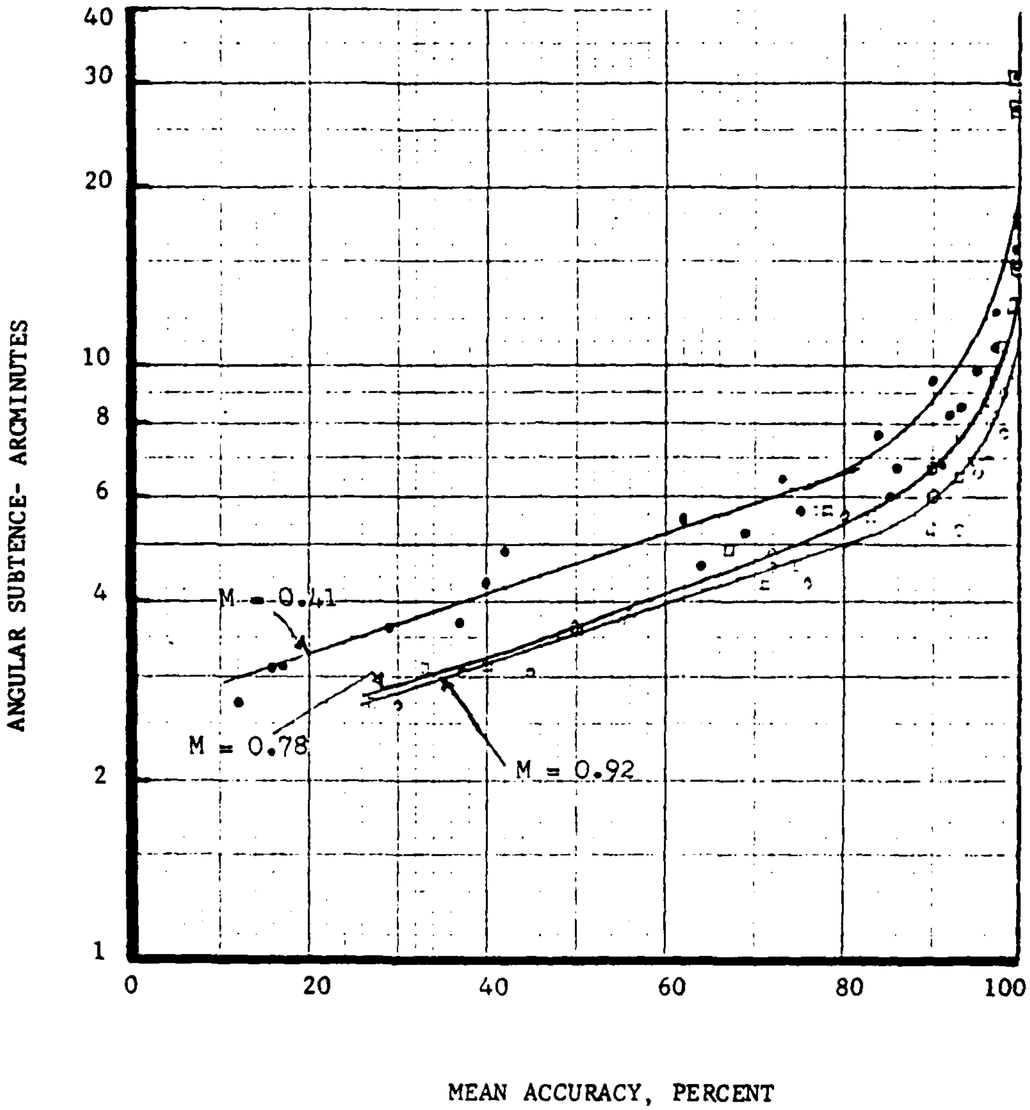



FIGURE 56. ANGULAR SUBTENSE REQUIREMENTS DETERMINED BY DOT MODULATION AND ACCURACY.

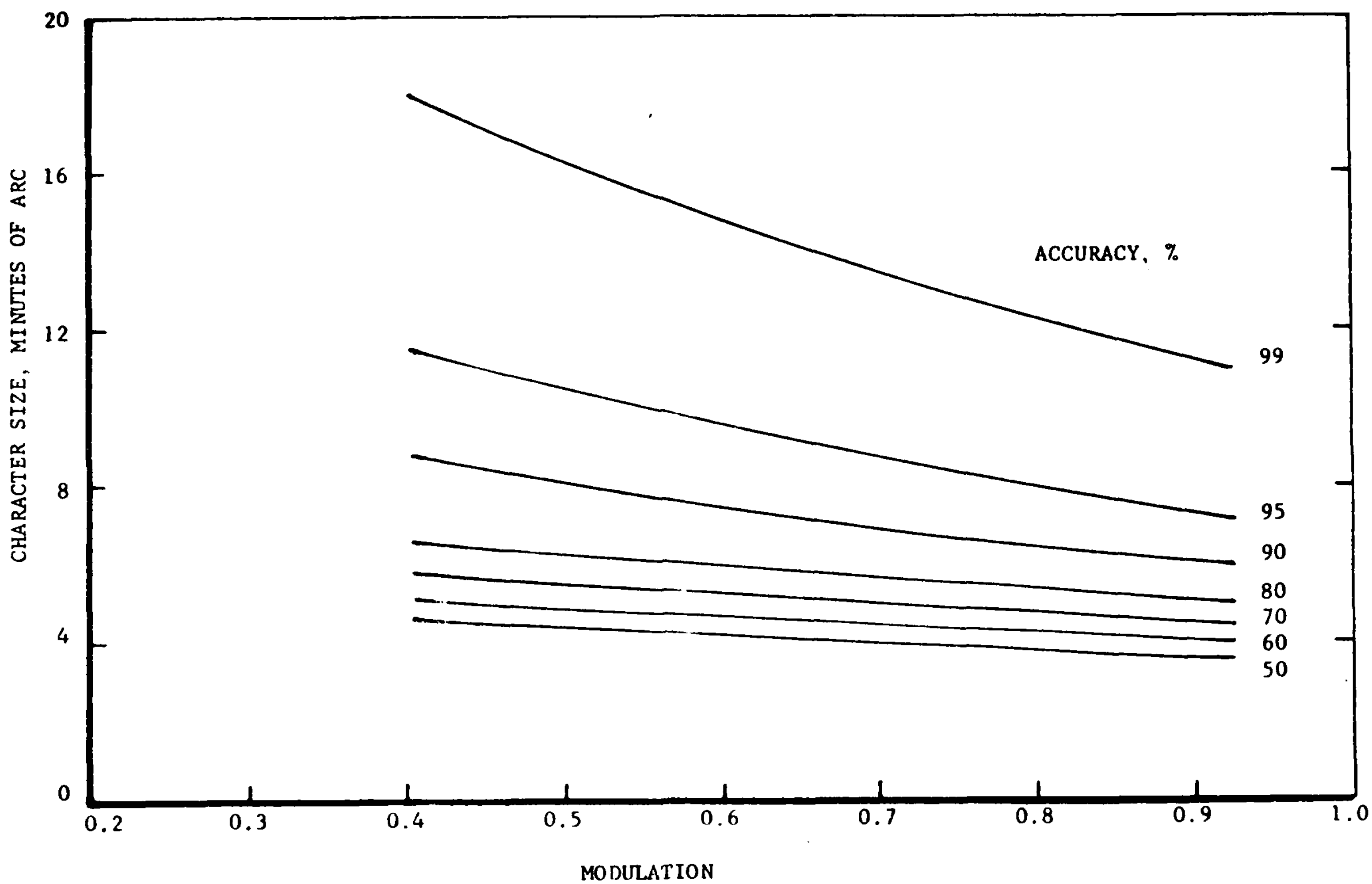



FIGURE 57. TRADEOFF BETWEEN MODULATION AND CHARACTER SIZE FOR CONSTANT LEGIBILITY

For example, if the ambient illuminance causes a decrease in modulation from 0.90 to 0.40, and if one is using a performance criterion of 99% accuracy, then the character size must be increased from 11 arcminutes to approximately 18 arcminutes. Other conversions can be estimated in a similar manner from Figure 57.

Thus, it is not possible to specify a required contrast in the absence of a known character size or vice versa. However, since contrast (or modulation) will undoubtedly decrease as the ambient illuminance increases, the final size determination can be made only after this modulation reduction is known or calculated, with such calculation based upon filter characteristics, ambient illuminance, directional reflectance, and display inherent luminance contrast.

It should be noted, in this context, that the absolute luminance of the displayed characters is not nearly as important as the modulation. Generally, it is desirable not to have the display average luminance greater than 10 times the background (adapting) luminance, nor less than 1/10 the background luminance under high ambient conditions. In the former case, violation of this rule of thumb results in the display becoming a glare source and also in reducing the existing dark adaptation level. In the latter case, adaptation to the higher ambient illuminance causes a reduction in sensitivity to the much darker display.

Minimum Luminance

The above discussion addressed contrast as a required minimum for legibility. These requirements tend to drive the maximum luminance required of the display.

However, there is a minimum luminance requirement needed for night operations under very low ambient illuminance. Under full moon conditions, the maximum natural illuminance is $3.45 \times 10^{-2}$ foot-candle (or $3.71 \times 10^{-1}$ lux). On a very dark, overcast night, the ambient illuminance can approach $10^{-5}$ foot-candle (or $1.08 \times 10^{-4}$ lux). Assuming a directional display reflectance of 50%, the background display luminance under this darkest night condition will be $5 \times 10^{-6}$ foot-lambert (or $1.7 \times 10^{-5}$ cd/m$^2$). To avoid reduction of dark adaptation by the crew, filtering or dimming of the display is necessary. Under the dark night condition, the display should be dimmable to $2.5 \times 10^{-3}$ foot-lambert ($8.6 \times 10^{-3}$ cd/m$^2$), assuming no other cockpit displays are more luminous. (If they are, then the EMMADS display should match them in luminance.)

Under the more typical night illuminance of about $5 \times 10^{-4}$ foot-candle ($5.4 \times 10^{-3}$ lux), the display should be dimmable to $2.5 \times 10^{-2}$ foot-lambert (or $8.6 \times 10^{-2}$ cd/m$^2$), assuming again that other cockpit displays are not more luminous.

Luminance levels should be controllable to provide adjustment to the ambient conditions such as to maintain a modulation between 90 and 100%. If this control is to be manually operated, then the luminance of the display should be logarithmically related to control movement (e.g., potentiometer turns).

## Refresh Rate

The display refresh rate should be chosen to avoid perceptible flicker, which is maximized under peripheral viewing in a dark surround. With displays having normal rise and decay times, a 60-Hz refresh is typically adequate. However, displays with extremely short rise and decay times are seen to flicker at higher refresh rates. This problem is compounded further by relative vibration between the viewer and the display, which can cause apparent strobing even at refresh rates as great as 200 or 300 Hz.

The best means to predict the refresh rate at which flicker will appear seems to be the following. The luminance amplitude/time function at any refresh rate is Fourier analyzed to determine the luminance power at the fundamental frequency. Note that this amplitude/time function must accurately convolve the refresh rate with the display's rise and fall times. If the luminance power at the fundamental temporal frequency is below the visual threshold fcr flicker, then the display will be seen as not flickering; however, if the luminance power is greater than the flicker threshold, then the display will be seen to flicker, assuming no relative vibration. The extent to which vibration may increase the required refresh rate is apparently not predictable in a quantitative fashion--the data simply do not exist. For example, for a red LED display, Riley (1977) found that a refresh rate of 200 Hz was necessary to prevent apparent flicker or break-up of the image.

Assuming that amplitude/time function is to be Fourier analyzed and compared with the observer's visual threshold, then the curves in Figure 58 can be used to establish an estimation of the required refresh rate. Assuming the selected display is not a LED, and that it has rise and fall times in excess of 100 μs, then a 60 Hz refresh rate should be adequate. Verification is desirable either by Fourier analysis, as described above, or by actual evaluation of the selected hardware.

Viewing Angle

Most displays are optimally viewed normal to their surfaces. Non-normal viewing typically results in a reduction of the modulation of the displayed image. Typically the geometric distortion is not critical for alphanumerics and vectorgraphics at angles ranging ±30 deg from the normal. However, reductions in image modulation can result in degraded observer performance, as shown in Figure 59 for both AC and DC plasma panels.

The design criteria for image angular subtense and dot modulation should be met for all likely viewing angles to avoid a degradation in observer performance.

Of course, installation to avoid direct glare from ambient illumination sources is critical for all viewing angles.

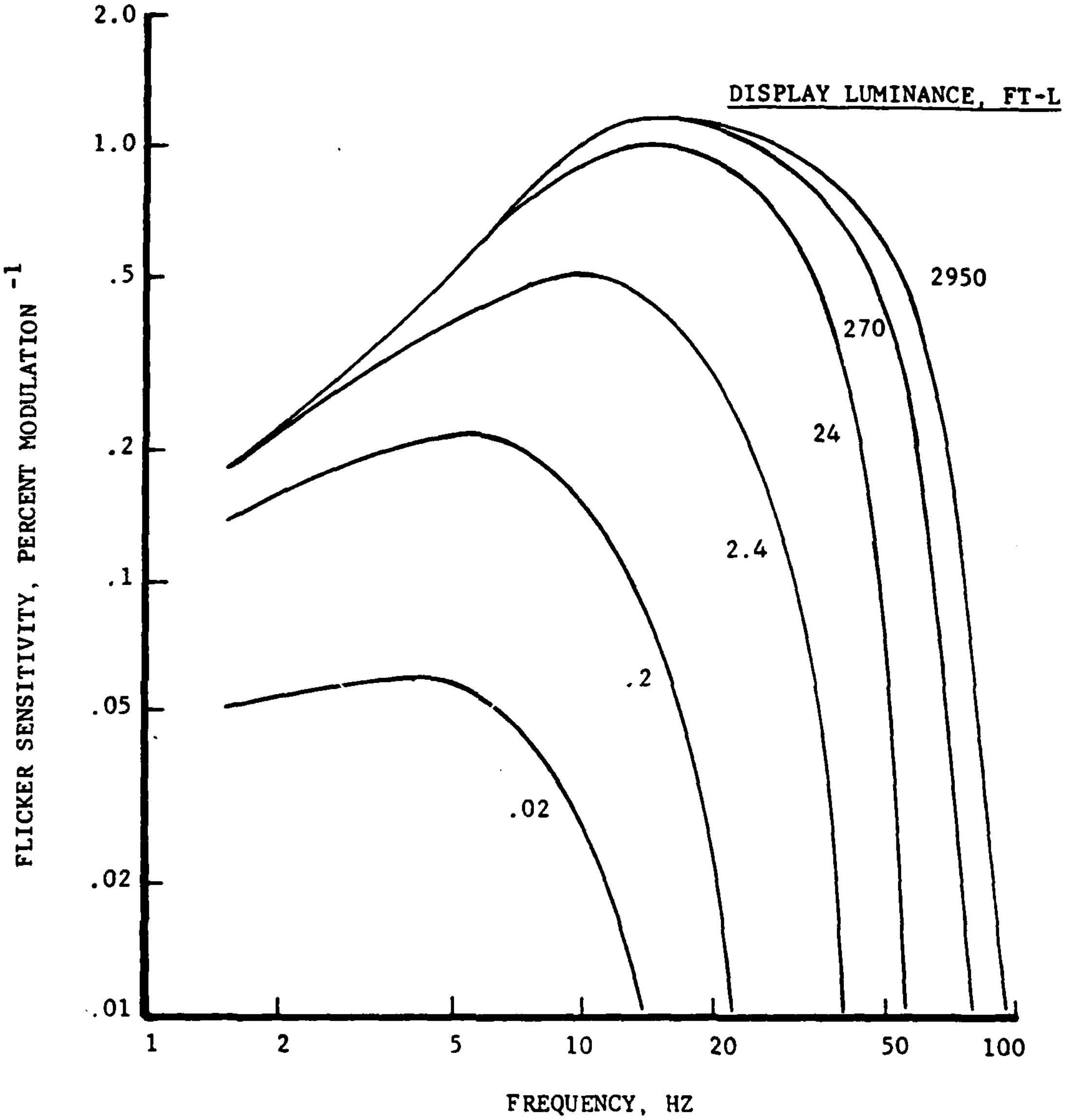



FIGURE 58. THRESHOLD FLICKER SENSITIVITY AS A FUNCTION OF MEAN DISPLAY LUMINANCE

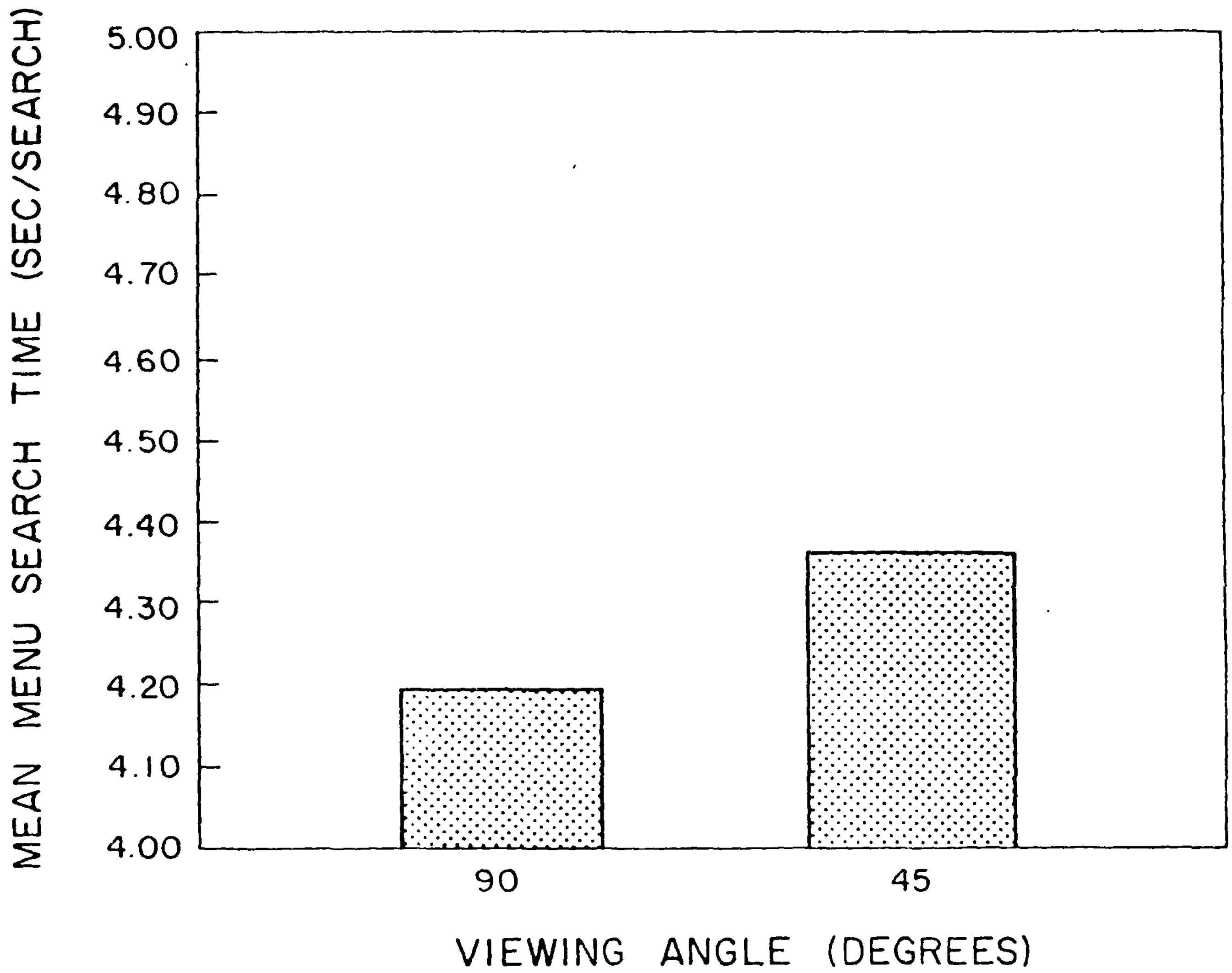



Figure 59. Effect of viewing angle on observer performance with plasma displays.

Uniformity

Uniformity of a display can best be defined in its absence, or by nonuniformity. Following the general approach of Goede (1978), three important types of nonuniformity can be meaningfully distinguished: large area nonuniformity, small area nonuniformity, and edge discontinuities.

Large area nonuniformity is a gradual change in luminance (or color) from one area of the display to another, such as center-to-edge or edge-to-edge comparisons and gradients.

Small area nonuniformity pertains to element-to-element changes in luminance (or color) over small areas.

Edge discontinuity refers to changes in luminance or color over an extended boundary.

While this attempt by Goede (1978) to classify nonuniformities is heuristically helpful, it does not discuss suitable metrics of measurement. Still to be defined are "large area" and "small area", "changes in luminance," and the like. While one might easily suggest candidate metrics for evaluation (e.g., edge gradient, acutance, rms luminance), none has been tested or justifiably recommended. Sherr's (1979) excellent text on electronic displays includes no mention of uniformity in its representative specification parameter set (p. 38).

The only logical position to take at this time is a heuristic one, based upon the observer's luminance discrimination capability. Using a luminance increase of 4% as a nominal threshold value, a reasonable set of requirements is as follows.

No adjacent dots, when commanded to the same luminance, should differ by more than 3%.

Maximum fluctuation in luminance, over the entire display, should not exceed 10% for dots commanded to the same luminance level.

Vectorgraphics

Only recently has attention been given to the visual requirements for line graphic displays. Rectangular coordinate form dot matrix displays will necessarily have some line edge irregularity at line orientations other than 0, 45, and 90 deg. The extent to which such "scalloping" is important depends generally on the observer's task. If the observer must accurately estimate the angular orientation of a line (e.g., horizon line), then such variable irregularity may become increasingly distracting as the dot spacing increases. However, the effect will be largely one of distortion and cosmetic appearance of the display, since accuracy in estimating angular orientation, with practice, is generally limited to 3-4 deg.

Should it be desirable to eliminate such edge scalloping, software/hardware combined techniques are available. For example, dots adjacent to the concave portion of the scalloped line can be partially illuminated, which results in a "softening" of the edge when viewed microscopically, but in a perceptual "sharpening" when viewed at normal viewing distances. This and toher techniques are often referred to as "antialiasing."

For the EMMADS, no such line graphic requirement appears needed. Rather, lines, conics, and curved sections, as well as filled bars, should merely meet the other display criteria of dot spacing, luminance, shape and uniformity.

## SUMMARY

A summary of the recommended display design criteria is shown in Table 8. Values for both static viewing and for the indicated vibration environment are included where there is need for distinction.

## CONTROL DESIGN CRITERIA

As stated above, it is assumed that controls will be depressable buttons, with programmable legends. The legend feedback of the control mode must conform to established criteria. If the display feedback is solely on the EMMADS, then the display criteria presented above apply. If the display feedback is on illuminated button legends, then the usual MIL-STD criteria should be used.

Accordingly, the following control criteria should be used for pushbutton designs, and relate solely to the control function.

Pushbutton depression should be accompanied by a sudden drop in force resistance, and actuation should be indicated immediately by the associated display.

Button size: 7 mm (diameter); 13 mm preferred

Edge-to-edge spacing: 18 mm; 25 mm preferred if gloves worn.

Resistance: 10-20 oz. preferred; 40 oz. maximum (Resistance should be elastic, starting low, building up to a maximum, and dropping suddenly to indicate activation; Chapanis and Kinkade, 1972)

Displacement: 3.5 mm; 7 mm maximum

Button Surface: concave, to prevent slippage

TABLE 8 - SUMMARY OF EMMADS DISPLAY DESIGN CRITERIA

| | STATIC VIEWING* | CH-47/SH-3A** VIBRATION ENVIRONMENT |
|---|---|---|
| CHARACTER SIZE | 11 Arcminutes, Minimum (.09 in. at 28 in.) | 39 arcminutes (.32 in. at 28 in.) |
| MATRIX SIZE | 7 x 9 minimum, 9 x 11 preferred | |
| CHARACTER FONT | LINCOLN/MITRE | |
| INTERDOT (EDGE-TO-EDGE) SPACING | .3 Arcminutes, maximum (.002 in. at 28 in.) | 1.0 Arcminutes, Maximum (.008 at 28 in.) |
| DOT SIZE (DIAMETER) | .7 Arcminutes, minimum (.006 in. at 28 in.) | 3.0 Arcminutes, Minimum ).024 in. at 28 in.) |
| DOT SHAPE | SQUARE | |
| DOT/BACKGROUND CONTRAST (MODULATION) | 80% A reduction in contrast requires an increase in character size. | |
| MINIMUM DOT LUMINANCE | $2.5 \times 10^{-2}$ ft-L ($8.6 \times 10^{-2}$ cd/m$^2$); $2.5 \times 10^{-3}$ ft-L ($8.6 \times 10^{-3}$ cd/m$^2$) preferred | |
| UNIFORMITY | 3% Adjacent Dots; 10% Overall | |
| REFRESH RATE | 60 HZ, minimum (other values may be required for display technologies other than EL) | |

* No relative motion between observer and display

** From Hutchins, 1972

# SECTION VIII - DISPLAY REQUIREMENTS

In this section a definition is developed to describe the necessary display hardware capability for the EMMADS Display Unit(s). This definition is driven by:

- The information content and formats contained in Figures 21 - 45, and
- The Human Factors Display Design Criteria presented in Section VIII

Together, these factors (plus other practical considerations) define a necessary size and resolution capability for the EMMADS display to provide "optimal" presentation of necessary information.

## DISPLAY SIZE

For sizing considerations, the engine display is used because of its large information content and overall complexity.

From the worst case engine format in Figure 28, the requirement for about 30 character spaces (horizontally) is apparent to accommodate the array of digital values at the bottom of the format. In this and other formats a minimum of 2 stroke widths is used between adjacent characters in the same parameter. A stroke width is defined as the maximum horizontal dimension of a single cell e.g. the width of the vertical portion of the letter "I". For this discussion a character space is defined as a 9 wide by 11 high array of cells comprising the character plus a 2 wide by 11 high space or an 11 x 11 array of cells. A full (horizontal) character space is used between adjacent sets of values e.g. between the left and right values of the same parameter or between the right hand value of one parameter and the left hand value of another. Horizontally, the message bar also requires just over 30 character spaces (3 message capsules of 9 characters each plus spaces).

Applying the character size criteria of the previous section (39 min; .32 in. at 28 in. viewing distances, based on an extreme vibration environment from the CH-47) to the 30 character horizontal display capacity requirement defines the need for a display width of about 9.6 in.

In a similar fashion, using a one-half character height minimum vertical spacing between adjacent lines of text or digital values and allowing about 2 in. for the analog scales, the vertical display requirement, using .32 in. characters is about 6.6 inches.

Thus to accommodate the worst case engine display format (Figure 28), using the recommended character size suitable for the CH-47 extreme vibration environment, a 6.6 in. by 9.6 in. display is required.

DISPLAY RESOLUTION

Two factors must be considered in determining a resolution requirement for the EMMADS display- alphanumeric symbology and analog tapes/bars. The minimum resolution requirement to construct a .32 in. high character using a 9 x 11 matrix is about 34 cells/in., for a 7 x 9 character only about 22 cells/in. are required. Some multiple of these resolutions would also be appropriate thus creating characters having multiple cell stroke widths, e.g. 18 x 22 or 14 x 18. These would require resolutions of 68 and 44 cells/in., respectively and would use a 4 cell array as the basic "cell" element. Higher order multiples (3, 4, 5 etc.) could also be used.

Although not documented in the HF literature regarding improved legibility, some aesthetic advantages can be realized in using multiple element cell construction.

This added resolution allows the deletion of one or more of the single elements of the cell to enhance curve smoothing and in general to reduce the "dot matrix" appearance of the symbols. This technique, although requiring additional software, results in symbology that approaches the appearance of stroke written characters. The alphanumerics used in Figures 21 - 45 exhibit a double stroke cell construction with minor deletions to enhance smoothing, etc.

The two-inch high vertical tapes used in the engine format are comparable in size to those used in the UH-60 and the YAH-64. With the exception of the PTIT indicator, most have a range from zero to about 125 units (either %, PSI or °C).

Operating on the assumption that some truncation and/or compression can be employed at the low end of each scale, a resolution of about 100 units is required on each analog indicator. For the 2 in. indication, this results in a minimum resolution requirement of about 50 cells/in.

Unless some higher order character block (beyond 7 x 9 or 9 x 11) is used, minimum resolution requirements are driven by the analog indicators which require about 50 cells/in.

EMMADS DEMONSTRATOR AND FLIGHT TEST MODELS

Implementation of the operating concepts, information requirements, and recommended design criteria generated thus far is necessarily contingent on the availability of a display medium compatible with the above requirements.

The left half of Table (9) summarizes the demonstrator character capacities for various character matrices (5 x 7, 7 x 9, 9 x 11 and 11 x 13) and vertical and horizontal line and character spacings. Since the demonstrator is a scaled down version of the display size required for flight conditions, the HF design criteria (regarding character size) will be excluded for this application.

By giving primary consideration to the horizontal character capacity, the optimum choice (satisfying format requirements with largest character size) appears to be the 9 x 11 character with a double stroke width horizontal and half character height vertical spacing. Figure 60 shows the character matrix and minimum spacings.

It is anticipated that a larger EL panel will be available for the flight test model of EMMADS. Present forecasts indicate this panel to be about 5.2 x 6.5 in. with 512 x 640 active cells (98.5 cells/in.). The increases in size and resolution (from the demonstrator to the proposed flight test panels) are proportionately almost identical. As shwon in the Flight-Test half of Table 9, character capacities of this size panel are almost identical to that of the Demonstrator if a double stroke character matrix is used. Thus the flight test display (as specified) should accommodate the same character requirements as the Demonstrator Panel if a double stroke character matrix (18 x 22) is used.

It should be noted that a single stroke 18 x 22 cell character could be used but the stroke width to height ratio (1:22) would create line widths too thin for good legibility.

| | DEMONSTRATOR 3.5" x 4.7" 68 CELLS/IN 240 x 320 CELLS | | | | FLIGHT-TEST 5.2" x 6.5" 98.5 CELLS/IN 512 x 640 CELLS | | | |
|---|---|---|---|---|---|---|---|---|
| CHARACTER BLOCK | 5 x 7 | 7 x 9 | 9 x 11 | 11 x 13 | 10 x 14 | 14 x 18 | 18 x 22 | 22 x 26 |
| CHARACTER SIZE-IN | .07 x .10 | .10 x .13 | .13 x .16 | .16 x .19 | .10 x .14 | .14 x .18 | .18 x .22 | .22 x .26 |
| CHARACTER HT-MIN | 12.3 | 16 | 19.6 | 23.3 | 17.2 | 22 | 27 | 31.9 |
| TOTAL CHARACTER BLOCKS | 34.3 x 64 | 26.9 x 47 | 21.8 x 36.2 | 18.5 x 29.4 | 36.6 x 64 | 28.8 x 46.4 | 23.6 x 36.1 | 19.6 x 29.5 |
| CHARACTER CAPACITY WITH: | | | | | | | | |
| SINGLE STROKE HORIZ. & .5 CHAR. HT VERT SPACING | 22 x 53.3 | 17.1 x 40 | 14 x 32 | 12 x 26.6 | 24.4 x 53.3 | 19 x 40 | 15.5 x 32 | 13.1 x 26.6 |
| 1.5 STROKE HORIZ. & .5 CHAR. HT VERT SPACING | N/A | N/A | N/A | N/A | 24.4 x 49.2 | 19 x 37.6 | 15.5 x 30.5 | 13.1 x 25.6 |
| DOUBLE STROKE HORIZ. & FULL CHAR. HT VERT SPACING | 17.1 x 45.7 | 13.3 x 35.6 | 10.9 x 29.1 | 9.2 x 24.6 | 18.3 x 45.7 | 14.2 x 35.6 | 11.6 x 29.1 | 9.8 x 24.6 |

TABLE 9 - SUMMARY OF EMMADS DEMONSTRATOR AND FLIGHT TEST DISPLAY CAPABILITIES

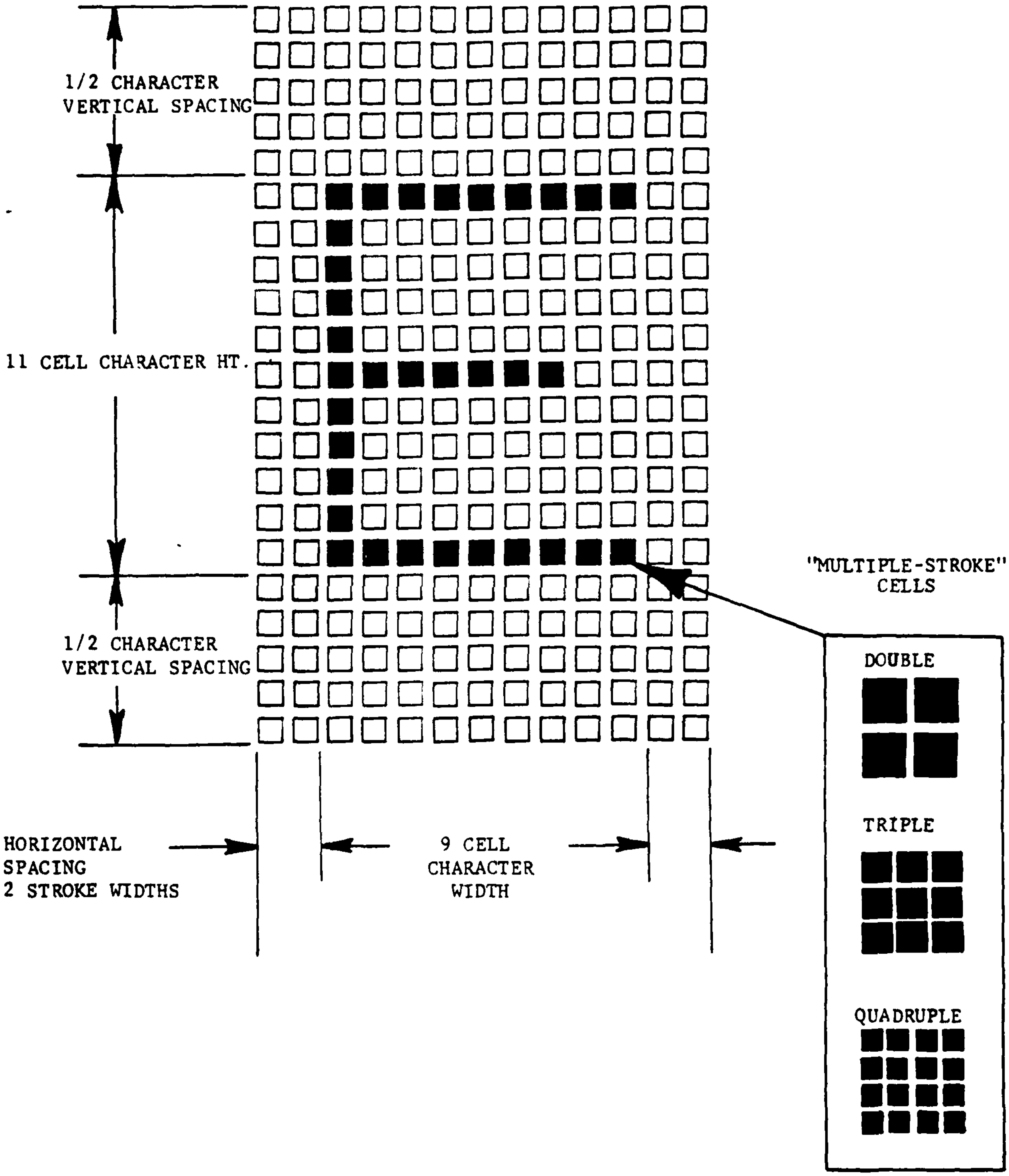



FIGURE 60 - 9 x 11 CHARACTER WITH HORIZONTAL AND VERTICAL SPACINGS

These double stroke characters proposed for the Flight Test Display will subtend about 27 $\widehat{\text{min}}$. resulting in a character height of about .22 inches. This size is somewhat less that that recommended in the HFE Design Criteria. However, the design criteria were based on a worst case vibration environment for the CH-47. Further investigation is required to a) determine a more representative overall vibration level and b) to operationally evaluate the legibility of smaller (than recommended) characters in this environment.

For comparison, the character set used on the display formats of Figures 21 - 45 is constructed from a 14 x 18 matrix using the double stroke technique. The character height is just under one quarter inch (.244 in.) and subtends a visual angle of 30 $\widehat{\text{min}}$. at a viewing distance of 28 in.

## SECTION IX - RECOMMENDATIONS FOR FURTHER TESTING

Certain compromises and assumptions were made in designing and conducting the Basic Test Program as mentioned earlier. To validate these Basic results and to verify other display design criteria it is suggested that additional testing be performed. Any testing with the EMMADS Demonstrator hardware is precluded by the non-availability of a "working" system until very late in the 6.2 program. Program scope is also not compatible with such testing during this time frame.

As an alternative, with regard only to the hardware availability problem, testing could be conducted using a simulated EMMADS display in the form of the GETS gas plasma display or 35 mm slides taken from same. An operational scenario is presently available (in 35 mm color slides) which depicts APU and Engines start sequences plus representative normal operating and faulted subsystem displays.

With appropriate vibration apparatus (for either operator or display) a test program could be performed to evaluate and/or validate (individually or collectively)

- The effectiveness of the composite information handling formats
- The effect of vibration on the legibility of the proposed (or other) character sizes
- The overall system operation with respect to operator workload and system effectiveness
- The effect of display luminance/contrast/refresh on any of the above

As mentioned, present program/scope do not provide for such system type testing at this time. However, this testing could be accomplished in the form of a follow-on effort to the feasibility demonstration or as a pre-flight test validation prior to (or during) aircraft installation/ hardware modification, etc.

APPENDICES

A. BIBLIOGRAPHY OF LITERATURE SURVEY FOR MISSION/WORKLOAD ANALYSES

B. SUBSYSTEM/PARAMETER IDENTIFICATION, SUMMARY OF COMPLETED FORMS

C. INITIAL INFORMATION CONTENT FIGURES/FT. CAMPBELL CRITIQUE SHEETS

D. EMMADS SYSTEM DESCRIPTION FOR FT. CAMPBELL FLIGHT CREW INTRODUCTION

E. INSTRUCTIONS FOR PARTICIPANTS IN BASIC TESTING PROGRAM

F. REFERENCES FOR HFE DESIGN CRITERIA RESEARCH

APPENDIX A

WORKLOAD/MISSION ANALYSIS LITERATURE REVIEW BIBLIOGRAPHY


| | |
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| ITR ECOM-0404-1 | UTILITY TACTICAL TRANSPORT AIRCRAFT SYSTEM (UTTAS) COCKPIT CONFIGURATION STUDY-HEGLIN AND MURPHY |
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# APPENDIX B

## SUBSYSTEM/PARAMETER IDENTIFICATION
## SUMMARY OF COMPLETED FORMS FOR CH-47C, UH-60A, OH-58C AND YAH64

HELICOPTER: CH-47-C



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| ENGINE (1 & 2) | GAS PRODUCER SPEED-N1% | | | ALL | | X | X | | | X | | | |
| | POWER TURBINE INLET TEMP - °C | | | ALL | | X | X | | | X | | | |
| | TORQUE - % | | X | | | | | | | X | | | AUDIO AT LIMIT |
| | OIL PRESSURE - PSI | | | ALL | | X | X | | | X | | | |
| | OIL TEMPERATURE - °C | | | ALL | | X | X | | | X | | | |
| | OIL LEVEL - LOW | | | ALL | | X | | | | | X | | |
| | CHIP DETECTION | | | ALL | | X | | | | | X | | |
| | CONDITION LEVER ERROR - N1 CONT | | | ALL | | X | | | | | X | | |

HELICOPTER: CH-47C



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| FUEL (LEFT & RIGHT) | QUANTITY (FWD, MAIN, AFT, TOTAL)-POUNDS | | | ALL | | | X | | X | | | | SCHEMATIC DIAGRAM |
| | QUANTITY - LOW | | | ALL | | X | | | | | X | | |
| | LINE PRESSURE - LOW | | | ALL | | X | | | | | X | | AUDIO |
| | AUX BOOST PUMP PRESSURE - LOW | | | ALL | | X | | | | | X | | |

HELICOPTER: CH-47C



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| TRANSMISSION | | | | | | | | | | | | | |
| | ROTOR - RPM | | X | | | | | | | X | | | AUDIO AT LIMIT |
| | OIL PRESSURE (FWD, AFT, COMBINING, ENG 1/2) - PSI | | | ALL | | | X | | X | | | | SCHEMATIC DIAGRAM |
| | OIL PRESSURE - LOW | | | ALL | | X | | | | | X | | |
| | OIL TEMP (FWD, AFT, COMBINING, ENG 1/2) - °C | | | ALL | | | X | | X | | | | SCHEMATIC DIAGRAM |
| | OIL TEMP - HOT | | | ALL | | X | | | | | X | | |
| | CHIP DETECTION | | | ALL | | X | | | | | X | | |

HELICOPTER: CH-47C



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| ELECTRICAL | | | | | | | | | | | | | |
| | GENERATOR - OFF | | | ALL | | X | | | | | X | | AUDIO |
| | GENERATOR LOAD | | | ALL | | | X | | X | | | | |
| | AC EXTERNAL POWER-ON | | | ALL | | X | | | | | X | | |
| | DC RECTIFIER LOAD | | | ALL | | | X | | X | | | | |
| | RECTIFIER - OFF | | | ALL | | X | | | | | X | | |
| | DC EXTERNAL POWER -ON | | | ALL | | X | | | | | X | | |

HELICOPTER: CH-47C



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| HYDRAULIC | | | | | | | | | | | | | |
| | FLIGHT CONTROL | | | | | | | | | | | | |
| | PRESSURE - PSI | | | ALL | | | X | | X | | | | AUDIO AT LIMIT |
| | BOOST - OFF | | | ALL | | X | | | | | X | | |
| | UTILITY PRESSURE-PSI | | | ALL | | | X | | X | | | | |
| | CYCLIC TRIM ACTUATOR | | | | | | | | | | | | |
| | POSITION (FWD,AFT) | | | | | | | | | | | | |
| | KNOTS | | | ALL | | | X | X | | | | | |
| | SAS - OFF | | | ALL | | X | | | | | X | | |

HELICOPTER: CH-47C



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| MISCELLANEOUS | | | | | | | | | | | | | |
| | HEATED - HOT | | | ALL | | X | | | | | X | | |
| | RIGHT LANDING GEAR WHEEL DEPHASED | | | GND & PRE LAND | | X | | | | | X | | |
| | PARKING BRAKE-ON | | | GND & PRE LAND | | X | | | | | X | | |
| | CARGO HOOK - OPEN | | | ALL FLT | | X | | | | | X | | |
| APU | | | | | | | | | | | | | |
| | TURBINE - RPM | | | GND & PRE T/O | | | X | X | | | | | |
| | OVERSPEED | | | ALL | | X | | | | | X | | |
| | EXHAUST GAS TEMP-HIGH | | | ALL | | X | | | | | X | | |
| | OIL PRESSURE - LOW | | | ALL | | X | | | | | X | | |

HELICOPTER: UH-60A



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| ENGINE | | | | | | | | | | | | | |
| | POWER TURBINE SPEED | | | | | | | | | | | | |
| | N2% | | | ALL | | X | X | | | X | | | |
| | GAS PRODUCER SPEED | | | | | | | | | | | | |
| | N1% | | | ALL | | X | X | | | X | | | |
| | ENGINE OUT | | | ALL | | X | | | | | | X | AUDIO |
| | TURBINE GAS TEMP-°C | | | ALL | | X | X | | | X | | | |
| | TORQUE - % | | X | | | | | | | X | | | AUDIO AT LIMIT |
| | OIL TEMP - °C | | | ALL | | X | X | | | X | | | |
| | OIL TEMP - HOT | | | ALL | | X | | | | | X | | |
| | OIL PRESSURE - PSI | | | ALL | | X | X | | | X | | | |
| | OIL PRESSURE - LOW | | | | | X | | | | | X | | |

HELICOPTER: UH-60A



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| ENGINE (CONT'D) | | | | | | | | | | | | | |
| | CHIP DETECTION | | | ALL | | X | | | | | X | | |
| | OIL FILTER DIFFER-ENTIAL PRESSURE-OIL FILTER BYPASS | | | ALL | | X | | | | | X | | |
| | ANTI-ICE/START BLEED VALVE-ANTI-ICE ON | | | ALL | | X | | | | | X | | |
| | INLET TEMP-INLET ANTI-ICE ON | | | ALL | | X | | | | | X | | |
| | START CONTROL VALVE ENGINE STARTER | | | START | | X | | | | | X | | |

HELICOPTER: UH-60A



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| FUEL | QUANTITY (L&R MAIN, | | | | | | | | | | | | |
| (LEFT & RIGHT) | FWD & REAR AUX) LBS. | | | ALL | | X | X | | X | | | | |
| | QUANTITY - LOW | | | ALL | | X | | | | | X | | |
| | AUX EMPTY | | | | | | | | | | | | |
| | FILTER DIFFERENTIAL | | | | | | | | | | | | |
| | PRESSURE - FUEL | | | | | | | | | | | | |
| | FLTR BYPASS | | | ALL | | X | | | | | X | | |
| | BOOST PUMP PRESSURE- | | | | | | | | | | | | |
| | FUEL PRESS LOW | | | ALL | | X | | | | | X | | AUDIO |
| | PUMP SW & APU | | | | | | | | | | | | |
| | T-HANDLE SW- | | | | | | | | | | | | |
| | PRIME BOOST PUMP ON | | | ALL | | X | | | | | X | | |

HELICOPTER: UH-60A



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TRANSMISSION | | | | | | | | | | | | | |
| | ROTOR- % RPM | | X | | | | | | | X | | | |
| | ROTOR-OVERSPEED | | | ALL | | X | | | | | X | | AUDIO |
| | ROTOR - LOW ROTOR RPM | | | ALL | | X | | | | | X | | AUDIO |
| | M TRANSMISSION OIL TEMP - °C | | | ALL | | X | X | | X | | | | SCHEMATIC |
| | M TRANSMISSION OIL TEMP - HOT | | | ALL | | X | | | | | X | | |
| | M TRANSMISSION OIL PRESSURE - PSI | | | ALL | | X | X | | X | | | | SCHEMATIC |
| | M TRANSMISSION OIL PRESS - LOW | | | ALL | | X | | | | | X | | |
| | INTERMEDIATE TAIL ROTOR DRIVE OIL TEMP- INT XMSN OIL TEMP | | | ALL | | X | X | | X | | | | SCHEMATIC |

HELICOPTER: UH-60A 

| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| TRANSMISSION (CONTD.) | TAIL ROTOR OIL TEMP - TAIL XMSN OIL TEMP | | | ALL | | X | X | | X | | | | SCHEMATIC |
| | CHIP DETECTION (MAIN MDL SUMP, INPUT LH/RH, ACCESS LH/RH, INTM XMSN, TAIL XMSN) | | | ALL | | X | | | | | X | | SCHEMATIC |
| | MAIN ROTOR - GUST LOCK | | | ALL | | X | | | | | X | | |
| | TAIL ROTOR CONTROL CABLE-TAIL ROTOR QUADRANT | | | ALL | | X | | | | | X | | SCHEMATIC |

HELICOPTER: UH-60A



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| ELECTRICAL (1 & 2) | GENERATOR OUTPUT-GEN | | | ALL | | X | X | | X | | | | |
| | APU GENERATOR OUTPUT & CONNECTION - APU GEN ON | | | ALL | | X | | | | | X | | |
| | GENERATOR MAIN BEARING WEAR-GEN BRG | | | ALL | | X | | | | | X | | |
| | AC ESSENTIAL BUS-OFF | | | ALL | | X | | | | | X | | |
| | EXTERNAL PWR RECEPTACLE - EXT PWR CONNECTED | | | ALL | | X | | | | | X | | |
| | DC CONVERTER OUTPUT-CONV | | | ALL | | X | | | | | X | | |

HELICOPTER: UH-60A



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| ELECTRICAL | | | | | | | | | | | | | |
| (CONT'D) | DC ESSENTIAL BUS- | | | | | | | | | | | | |
| | OFF | | | ALL | | X | | | | | X | | |
| | BATTERY LOW CHARGE | | | ALL | | X | | | | | | X | |
| | BATTERY OVERCHARGE | | | | | | | | | | | | |
| | & OVERTEMP-BATTERY | | | | | | | | | | | | |
| | FAULT | | | ALL | | X | | | | | X | | |

HELICOPTER: UH-60A



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| HYDRAULIC (1 & 2) | PUMP PRESSURE - HYD PUMP | | | ALL | | X | X | | X | | | | |
| | BACK UP PUMP-ON | | | ALL | | X | | | | | X | | |
| | PRIMARY SERVO PRESSURE - PSI | | | ALL | | X | X | | X | | | | AUDIO |
| | TAIL ROTOR SERVO-ON | | | ALL | | X | | | | | X | | |
| | YAW & COLLECTIVE BOOST SERVO PRESS-OFF | | | ALL | | X | | | | | X | | AUDIO |
| | FLUID RESERVOIR-LOW | | | ALL | | X | | | | | X | | |
| | BACK-UP RESERVOIR-LOW | | | ALL | | X | | | | | X | | |

HELICOPTER: UH-60A



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MISCELLANEOUS | | | | | | | | | | | | | |
| | STABILATOR POSITION ERROR-STABILATOR | | | ALL | | X | | | | | X | | |
| | PITCH BIAS ACTUATOR-FAIL | | | ALL | | X | | | | | X | | |
| | SAS OFF | | | ALL | | X | | | | | | X | |
| | PITCH TRIM SERVO-TRIM FAIL | | | ALL | | X | | | | | X | | |
| | ROLL/YAW TRIM ACTUATOR-FLT PATH STAB | | | ALL | | X | | | | | X | | |
| | PILOT HEAT CURRENT-(LFT, RT) PILOT HEAT | | | ALL | | X | | | | | X | | |
| | M. ROTOR BLADE DEICE -FAIL | | | ALL | | X | | | | | X | | |

HELICOPTER: UH-60A



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| MISCELLANEOUS | TAIL ROTOR DE-ICE | | | | | | | | | | | | |
| (CONTD.) | FAIL | | | ALL | | X | | | | | X | | |
| | BLADE DE-ICE | | | | | | | | | | | | |
| | MR DE-ICE FAULT | | | ALL | | X | | | | | X | | |
| | NO. 2 ENG INLET | | | | | | | | | | | | |
| | ICE PROBE-ICE | | | | | | | | | | | | |
| | DETECTED | | | ALL | | X | | | | | X | | |
| | CARGO HOOK | | | | | | | | | | | | |
| | RELEASE SWITCH | | | | | | | | | | | | |
| | HOOK ARMED | | | ALL | | X | | | | | X | | |
| | CARGO HOOK LEAD BEAM | | | | | | | | | | | | |
| | CARGO HOOK OPEN | | | ALL | | X | | | | | X | | |
| | PARKING BRAKE-ON | | | GND | | X | | | | | X | | |
| | LANDING LIGHT-ON | | | PRE-LAND | | X | | | | | X | | |

HELICOPTER: OH-58C



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| ENGINE | GAS PRODUCER SPEED - N1% | | | ALL | | X | X | | | X | | | |
| | ENG OUT | | | ALL | | X | | | | | | X | AUDIO |
| | POWER TURBINE SPEED - N2% | | | ALL | | X | X | | | X | | | |
| | TURBINE OUTLET TEMP - °C | | | ALL | | X | X | | | X | | | |
| | TORQUE - % | | X | | | | | | | | | | AUDIO AT LIMIT |
| | OIL PRESSURE - PSI | | | ALL | | X | X | | | X | | | |
| | OIL TEMP - °C | | | ALL | | X | X | | | X | | | |
| | OIL RESERVOIR LEVEL - LOW | | | ALL | | X | | | | | X | | |
| | CHIP DETECTION | | | ALL | | X | | | | | X | | |
| | AUTO REIGNITION SYS RELIGHT | | | ALL | | X | | | | | | X | |

HELICOPTER: OH-58C



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| FUEL | | | | | | | | | | | | | |
| | QUANTITY (MAIN TANK) - LBS | | | ALL | | X | X | | X | | | | |
| | 20 MIN REMAIN | | | ALL | | X | | | | | X | | AUDIO |
| | BOOST PUMP PRESSURE - LOW | | | ALL | | X | | | | | | X | AUDIO |
| | FILTER DIFF. PRESSURE - FUEL FTR BYP | | | ALL | | X | | | | | X | | |

HELICOPTER: OH-58C



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| TRANSMISSION | | | | | | | | | | | | | |
| | ROTOR RPM NR% | | X | | | | | | | X | | | |
| | ROTOR RPM - LOW | | | ALL | | X | | | | | | X | AUDIO |
| | OIL PRESSURE - PSI | | | ALL | | X | X | | | X | | | |
| | OIL PRESSURE - LOW | | | ALL | | X | | | | | X | | |
| | OIL TEMP - HOT | | | ALL | | X | | | | | X | | |
| | CHIP DETECTION | | | ALL | | X | | | | | X | | |
| | TAIL ROTOR GBX | | | | | | | | | | | | |
| | CHIP DETECTION | | | ALL | | X | | | | | X | | |
| HYDRAULIC | | | | | | | | | | | | | |
| | HYDRAULIC PRESSURE | | | | | | | | | | | | |
| | LOW | | | ALL | | X | | | | | | X | AUDIO |

HELICOPTER: OH-58C



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| ELECTRICAL | | | | | | | | | | | | | |
| | DC GEN LOAD-AMPS | | | ALL | | X | X | | X | | | | |
| | DC GEN VOLTAGE - HI/LOW | | | ALL | | X | | | | | X | | |
| | 115 VAC BUS POWER - FAIL | | | ALL | | X | | | | | X | | |
| MISCELLANEOUS | | | | | | | | | | | | | |
| | PRI DIRECTIONAL ANTI-TORQUE SYS JAMMED - JAM | | | ALL | | X | | | | | | X | |
| | PRI DIRECTIONAL ANTI-TORQUE SYS DISENGAGED-DISENG. | | | ALL | | X | | | | | X | | |

HELICOPTER: YAH-64



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ENGINE (1 & 2) | POWER TURBINE SPEED NP % | | | ALL | | X | X | | | X | | | |
| | ENGINE OUT | | | ALL | | X | | | | | | X | AUDIO |
| | GAS PRODUCER SPEED NG % | | | ALL | | X | X | | | X | | | |
| | TURBINE GAS TEMPERATURE - °C | | | ALL | | X | X | | | X | | | |
| | TORQUE - % | | X | | | | | | | X | | | AUDIO AT LIMIT |
| | ENGINE OIL PRESSURE-PSI | | | ALL | | X | X | | | X | | | |
| | OIL PRESSURE - LOW | | | ALL | | X | | | | | X | | |
| | ENGINE OIL TEMP-°C | | | ALL | | X | X | | | X | | | |
| | ENGINE OIL- HOT | | | ALL | | X | | | | | X | | |

HELICOPTER: YAH-64



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? CONTINUOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ENGINE (CONT'D.) | OIL FILTER DIFF. PRESSURE - OIL FTR BYP | | | ALL | | X | | | | | X | | |
| | CHIP DETECTION | | | ALL | | X | | | | | X | | |
| | ANTI-ICE BLEED VALVE | | | ALL | | X | | | | | X | | |
| | ANTI-ICE HEATING-HOT | | | ALL | | X | | | | | X | | |
| | INLET ICE FORMATION-ENG ICE | | | ALL | | X | | | | | X | | |
| | CHOP COLLAR POSITION ENGINE CHOP | | | ALL | | X | | | | | X | | |

| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| FUEL (FWD & AFT) | QUANTITY (TOTAL, FWD & AFT)-LBS | | | ALL | | X | X | | X | | | | |
| | FUEL LOW (FWD & AFT) | | | ALL | | X | | | | | X | | AUDIO |
| | BOOST PUMP PRESSURE ON | | | ALL | | X | | | | | X | | |
| | FILTER DIFF. PRESSURE FUEL FTR BYP | | | ALL | | X | | | | | X | | |
| | TRANSFER REFUELING VALVE - OPEN | | | ALL | | X | | | | | X | | |
| | EXTERNAL TANK FUEL QTY-EMPTY EXT TANKS | | | ALL | | X | | | | | X | | |
| | ENG FUEL PUMP PRESSURE - LOW | | | ALL | | X | | | | | | X | AUDIO |

HELICOPTER: YAH-64



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TRANSMISSION | | | | | | | | | | | | | |
| | ROTOR RPM-NR% | | X | | | | | | | X | | | |
| | LOW ROTOR RPM | | | ALL | | X | | | | | | X | AUDIO |
| | HIGH ROTOR RPM | | | ALL | | X | | | | | | X | AUDIO |
| | MAIN XMSN OIL PRESSURE - LOW | | | ALL | | X | | | | | X | | |
| | MAIN XMSN ACC GBX OIL PRES-OIL PRESS ACC PMP LOW | | | ALL | | X | | | | | X | | |
| | MAIN XMSN OIL TEMP-HOT | | | ALL | | X | | | | | X | | |
| | MAIN XMSN OIL QTY-LOW | | | ALL | | X | | | | | X | | |

| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| TRANSMISSION (CONTD) | NOSE GBX OIL PRESSURE-LOW | | | ALL | | X | | | | | X | | |
| | NOSE GBX OIL TEMP-HOT | | | ALL | | X | | | | | X | | |
| | INT TAIL GBX-HOT | | | ALL | | X | | | | | X | | |
| | TAIL ROTOR GBX-HOT | | | ALL | | X | | | | | X | | |
| | CHIP DETECTION (MAIN, NOSE GBX, ENG 1/2) | | | ALL | | X | | | | | X | | |
| | ROTOR BRAKE SWITCH-ON | | | START | | X | | | | | X | | |

HELICOPTER: YAH-64



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| HYDRAULIC | | | | | | | | | | | | | |
| | PRIMARY PUMP | | | | | | | | | | | | |
| | PRESSURE - PSI | | | ALL | | X | X | | X | | | | |
| | PRIMARY OIL | | | | | | | | | | | | |
| | PRESS - LOW | | | ALL | | X | | | | | | X | AUDIO |
| | PRIMARY MANIFOLD | | | | | | | | | | | | |
| | FILTER DIFF. | | | | | | | | | | | | |
| | PRESSURE - OIL | | | | | | | | | | | | |
| | FTR BYP PRI HYD | | | ALL | | X | | | | | X | | |
| | PRIMARY MANIFOLD | | | | | | | | | | | | |
| | RESERVOIR QTY- LOW | | | ALL | | X | | | | | X | | |
| | UTILITY PUMP | | | | | | | | | | | | |
| | PRESSURE - PSI | | | ALL | | X | X | | X | | | | |
| | UTIL PRESS - LO | | | ALL | | X | | | | | X | | |

HELICOPTER: YAH-64



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| HYDRAULIC | | | | | | | | | | | | | |
| (CONTD.) | UTILITY MANIFOLD | | | | | | | | | | | | |
| | FILTER DIFF PRESS | | | ALL | | X | | | | | X | | |
| | UTILITY MANIFOLD | | | | | | | | | | | | |
| | RESERVOIR QTY-LOW | | | ALL | | X | | | | | X | | |
| | UTILITY ACCUM | | | | | | | | | | | | |
| | PRESSURE - PSI | | | ALL | | X | X | | X | | | | |

HELICOPTER: YAH-64



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| ELECTRICAL | | | | | | | | | | | | | |
| | GEN A PHASE FEEDER CURRENT-AMPS | | | ALL | | X | X | | X | | | | |
| | GEN OUTPUT - HIGH OR LOW | | | ALL | | X | | | | | X | | |
| | AC EXT PWR RECEPTACLE DOOR-OPEN | | | ALL | | X | | | | | X | | |
| | TRANS/RECT OUTPUT CURRENT DC AMPS | | | ALL | | X | X | | X | | | | |
| | AC ESS BUS OR TRANS/ RECT VOLTAGE-FAIL | | | ALL | | X | | | | | X | | |
| | TRANS/RECT OPERATING TEMP - HOT | | | ALL | | X | | | | | X | | |

HELICOPTER: YAH-64



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| ELECTRICAL (CONTD.) | BATTERY TEMP- HOT | | | ALL | | X | | | | | X | | |
| | BATTERY- NOT CHARGING | | | ALL | | X | | | | | | BEFORE SHUTDOWN | |

HELICOPTER: YAH-64 

| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| MISCELLANEOUS | | | | | | | | | | | | | |
| | SHAFT DRIVEN COMPRESSOR PRESSURE-LOW | | | ALL | | X | | | | | X | | |
| | ENVIRON. CONTROL UNIT OUTPUT AIR-HOT | | | ALL | | X | | | | | X | | |
| | CANOPY ANTI-ICE TEMP - HOT | | | ALL | | X | | | | | X | | |
| | BLADE DE-ICE TIME, CONTROL TEMP, CURRENT LEAKAGE-FAIL | | | ALL | | X | | | | | X | | |
| | CANOPY DOOR-OPEN | | | ALL | | X | | | | | X | | |
| | SCAS - OFF | | | ALL | | X | | | | | X | | |
| | FORCE FEEL SYS-INOP | | | ALL | | X | | | | | X | | |

HELICOPTER: YAH-64



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| MISCELLANEOUS (CONT'D) | BACK UP CONTROL SYS - ON | | | ALL | | X | | | | | X | | |
| | BACK UP CONTROL SYS - FAIL | | | ALL | | X | | | | | | X | AUDIO |
| | TAIL WHEEL -UNLOCKED | | | ALL | | X | | | | | X | | |
| | STABILATOR SYS-FAIL | | | ALL | | X | | | | | X | | |
| | IR JAM - INOP | | | ALL | | X | | | | | X | | |
| | TRANSPONDER MODE 4 INT - NO REPLY | | | ALL | | X | | | | | X | | |

HELICOPTER: YAH-64



| SUBSYSTEM | PARAMETER/ INDICATION | PRIORITY | "WHEN" IS DISPLAY REQUIRED? | | | | | "HOW" IS INFORMATION MOST APPROPRIATELY DISPLAYED? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CONTIN-UOUSLY | FLT PHASE | NOT REQ'D | BY EXCEP. | UPON MANUAL REQUEST | ANALOG | DIGITAL | BOTH A & D | DISCRETE | DISCRETE PLUS PROCEDURES | OTHER: EXPLAIN |
| MISCELLANEOUS | | | | | | | | | | | | | |
| (CONTD.) | ARMAMENT, FIRE CONTROL | | | | | | | | | | | | |
| | (ROCKET, GUN, MISSILE, | | | | | | | | | | | | |
| | TADS VOICE CIPHER, | | | | | | | | | | | | |
| | PNVS) | | | ALL | | | X | | | | X | | SCHEMATIC |
| | FLT CONTROL | | | | | | | | | | | | |
| | COMPUTER-FAIL | | | ALL | | X | | | | | | X | AUDIO |
| APU | | | | | | | | | | | | | |
| | GAS PRODUCER SPEED | | | | | | | | | | | | |
| | NG% | | | START-UP | | | | | X | | | | |
| | APU-FAIL | | | START-UP | | X | | | | | X | | |
| | APU-ON | | | ALL | | X | | | | | X | | |

# APPENDIX C

## INFORMATION CONTENT FIGURES/PILOT CRITIQUE SHEETS WITH SURVEY INSTRUCTIONS FOR CH-47C, UH-60A, OH-58C AND YAH-64

ELECTRONIC MASTER MONITOR AND DISPLAY SYSTEM

PILOT/COPILOT CRITIQUE

EXPERIENCE:

CURRENT RATINGS: ____________ ____________ ____________

| HELICOPTER | UH-1 | AH-1 | OH-58 | CH-47 | UH-60 | AH-64 | NOE | NIGHT |
|---|---|---|---|---|---|---|---|---|
| HOURS | | | | | | | | |

Having read the included operational description of EMMADS please indicate (on each of the following figures) any comments you have regarding the INFORMATION CONTENT of the display. Keep in mind that the displays in the following figures do not necessarily reflect the final display design with regard to the size, location, orientation, etc. of the display elements. These "format" characteristics will be evaluated during the test phase of this program. Include in your comments the following:

- Additional Message Warning Capsules
- Additional parameters, indications, status, etc.
- The word "TREND" next to those parameters where advanced warning of an increasing (or decreasing) value would be desirable.
- The word "AUDIO" next to those indications whose visual presentation should be accompanied by an audio (tone) warning.
- Any other comments

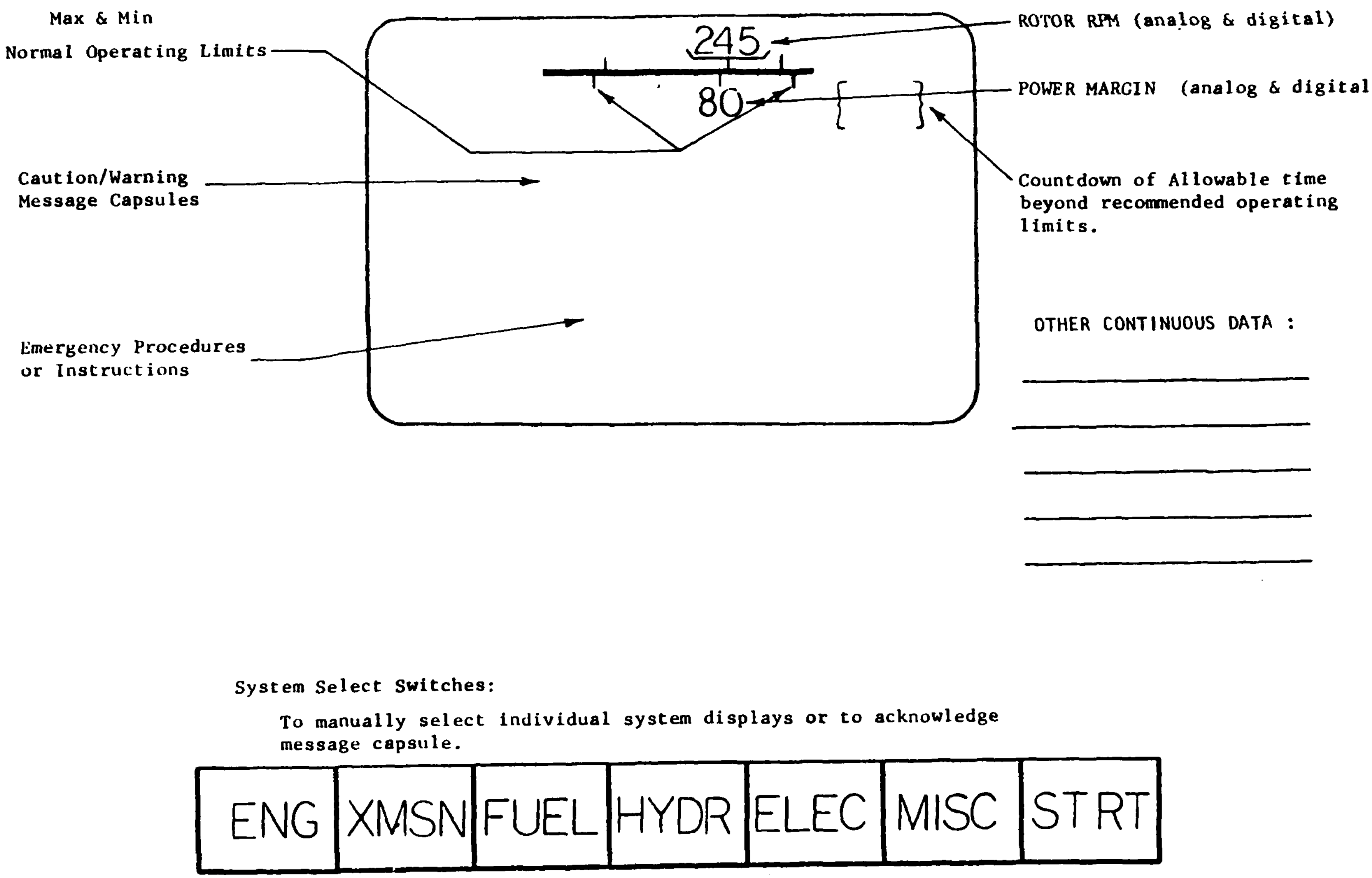
It is the intent of this survey to gather pilot/copilot opinion concerning the presentation of subsystem information. Your inputs will be used to modify and/or redefine the information requirements represented in these displays. Thank you for making available to us the value of your flight experience.

INFORMATION CONTENT FIGURES/

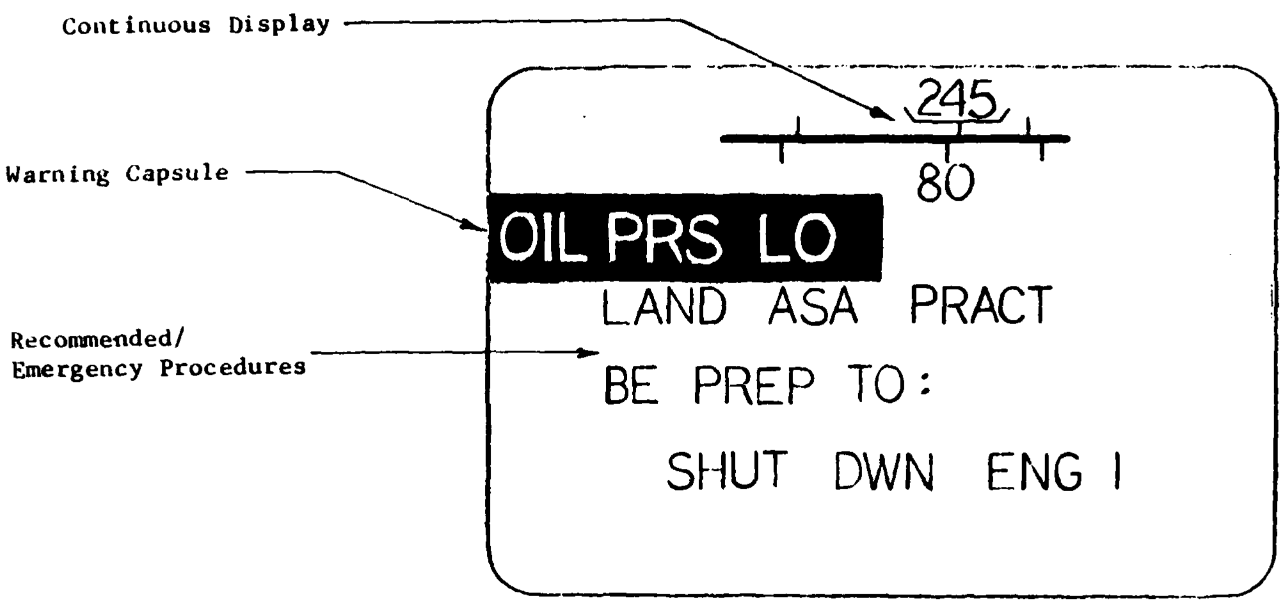
PILOT CRITIQUE SHEET FOR THE

CH-47C

CONTINUOUS FLIGHT DISPLAY



MESSAGE CAPSULE (ENG 1 - OIL PRS LO)
WITH INSTRUCTIONS

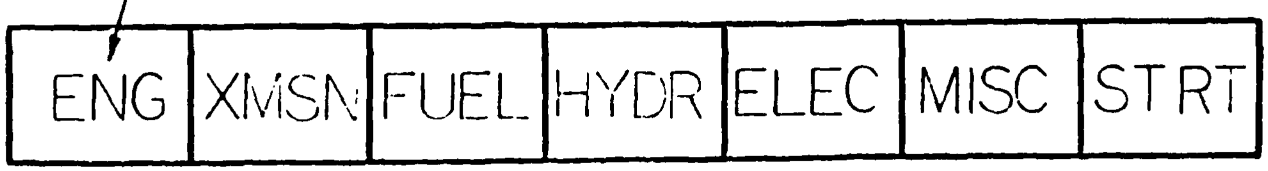



Procedure:

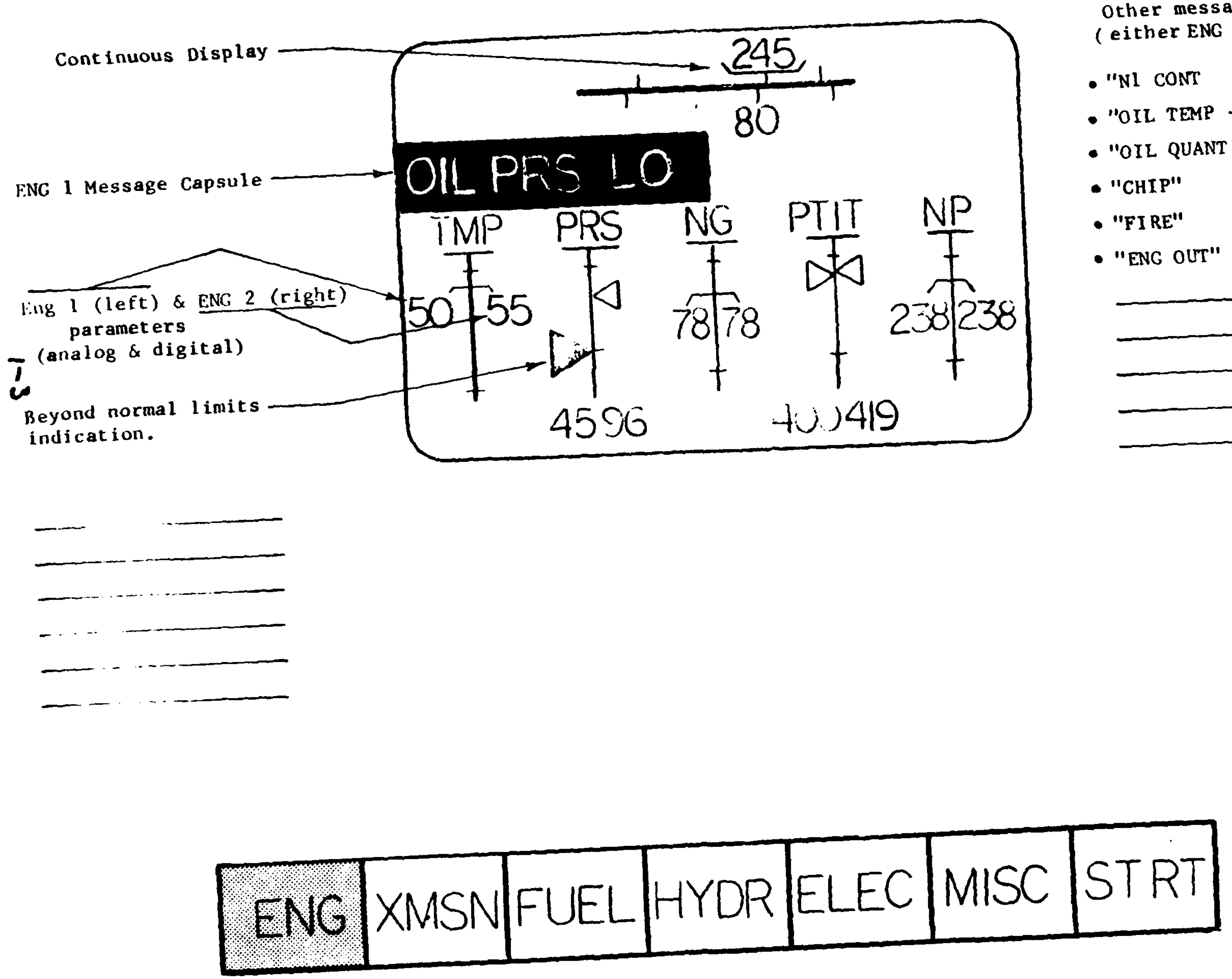
Acknowledge by depressing master caution switch or by selecting "ENG" display.

Result:

Display on next page



ENGINE SYSTEM DISPLAY
(with warning message capsule)




Other message capsules
(either ENG 1 or 2)

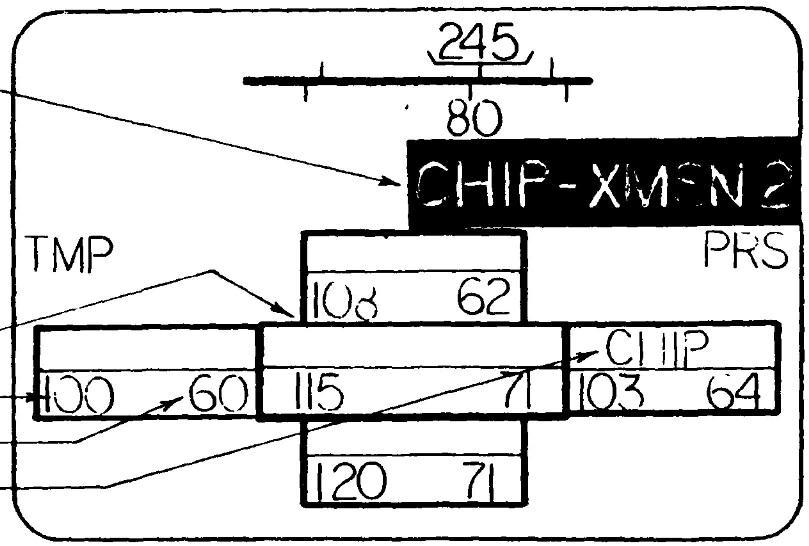
- "N1 CONT
- "OIL TEMP - HI"
- "OIL QUANT - LOW"
- "CHIP"
- "FIRE"
- "ENG OUT"

TRANSMISSION SYSTEM DISPLAY
(with warning message capsule)

Message Capsule
(chip-Eng 2 XMSN)

Transmission status display
including:

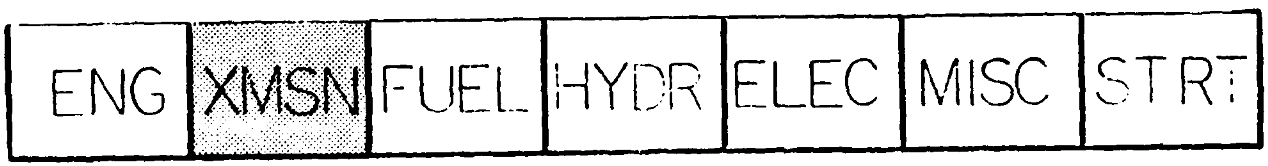
- Location schematic
- Oil temp (digital, Left)
- Oil pres (digital, Right)
- Individual message capsule




Other message capsules:

- Oil temp - HI
- Oil pres - LO
- Oil pres - HI

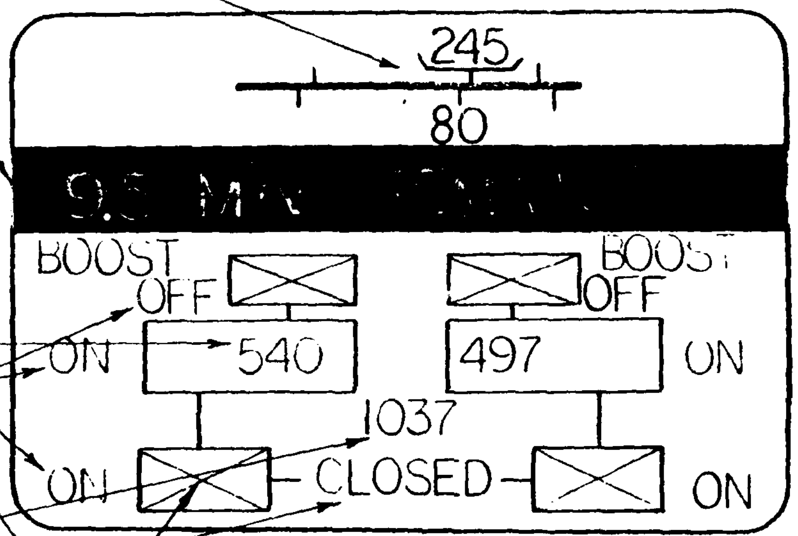
Warning message has been acknowledged
resulting in this display.



FUEL SYSTEM DISPLAY
(With caution message capusle)

Continuous Display

Fuel sys caution capsule
(illuminates at preset value &
continues to count down)




Fuel status display including:

- Tank Schematic
- Pounds remaining in ea.
- Boost pump status
- "X-FEED VALVE" status
- Total quantity remaining
- ("AUX") tanks empty

Other Message capsules:

- "RANGE REMAINING" (Pilot preset value)
- "PRESSURE LOW"
- "X-FEED VALVE" (action req'd.)
- "BOOST PUMPS" (action req'd.)

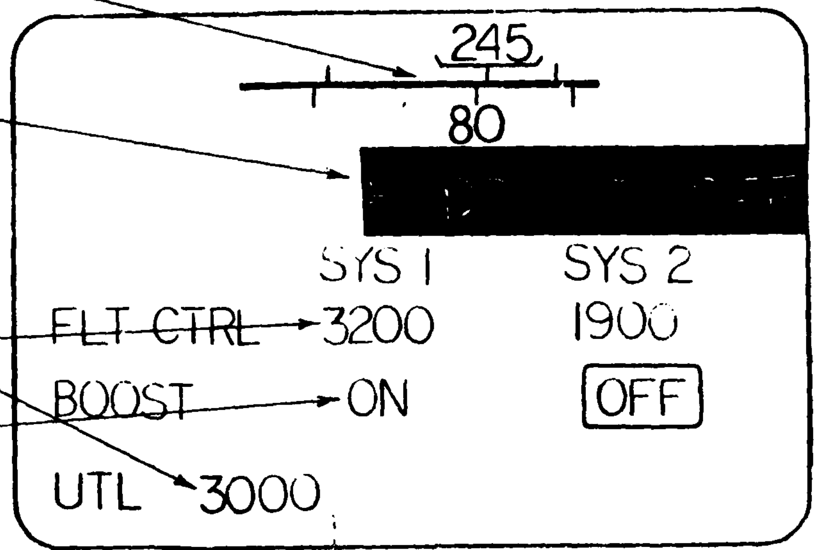
Catuion message has been acknowledged resulting in this display

| ENG | XMSN | FUEL | HYDR | ELEC | MISC | STRT |
|---|---|---|---|---|---|---|

HYDRAULIC SYSTEM DISPLAY

Continuous Display

Message Capsule




HYD sys display including:

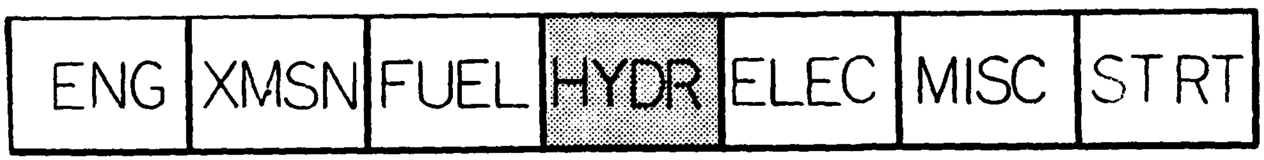
- FLT CTRL PRS - digital
- UTILITY PRS - digital
- BOOST - status

Message capsules:

- "BOOST OFF"
- "PRESSURE LOW" (FLT CTRL/UTIL)

1-6

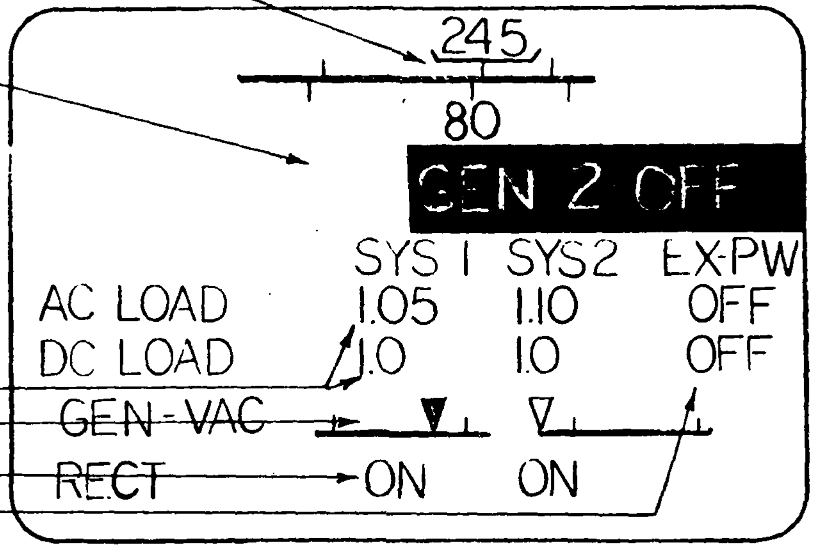
This display appears when the "HYD BST OFF" capsule is acknowledged



## ELECTRICAL SYSTEM DISPLAY

Continuous Display

Message Capsule




Electrical Status Display including:

- AC & DC LOAD - digital
- GENERATOR - analog
- RECTIFIER - status
- EXTERNAL PWR - status

Message capsules:

EXT PWR OFF

RECT OFF

This display appears when the "GEN 2 OFF" capsule is acknowledged

Checklist items, upon acknowledgement from system, receive check at right of display then disappear when next checklist item is acknowledged. A new item then appears at bottom of display.
Items are acknowledged by actuation of specified switch e.g. APU START SW to APU or by depression of "STRT" button. "STRT" button is used to verify accomplishment of items requiring pilot/crew activity e.g. "INTERPHONE CHECK".

APU START

CONNECT FOR GPU START ✓

BATTERY SW - ON

INTERPHONE CHECK

(EMMADS) SYSTEM TEST

POST FIRE GUARD

APU START SW - APU

GND-APU-AGB SW - START

APU START SW - START (HOLD, RELEASE)

—— APU RUNNING ——

"APU RUNNING" takes place of "APU START" and remains at top of display until checklist is completed.

GND-APU-AGB SW - RELEASE

GEN CTRL SW - ON

HYD UTILITY SW - AS REQ'D.

FLT CTRLS - CHECK

AVIONICS - ON

POSITION LIGHTS - CHECK

. . . ,

ETC

ENGINE 1 START DISPLAY

(Initiated by ENG condition lever in "GND" setting)

ENG 1 start instructions:

Each item is acknowledged by depressing strt button or by status of req'd switch actuation e.g. "START FUEL SW - OPEN". As each item is acnkowledged by the system, a check will appear on the right edge of the display. Upon performing the next item, the previous will disappear from the top of the display and the entire list will shift up one line, exposing a new item. After IGN ON is performed, START SW ON will erase IGN SW instruction and the N1 & PTIT tapes will appear.

START ENG 1

ENG 1 - AREA CLEAR ✓

ENG COND. LEVER - GND

L. MAIN FUEL PUMP - ON

X-FEED VALVE - OPEN

START FUEL SW - OPEN

IGN SW. - ON

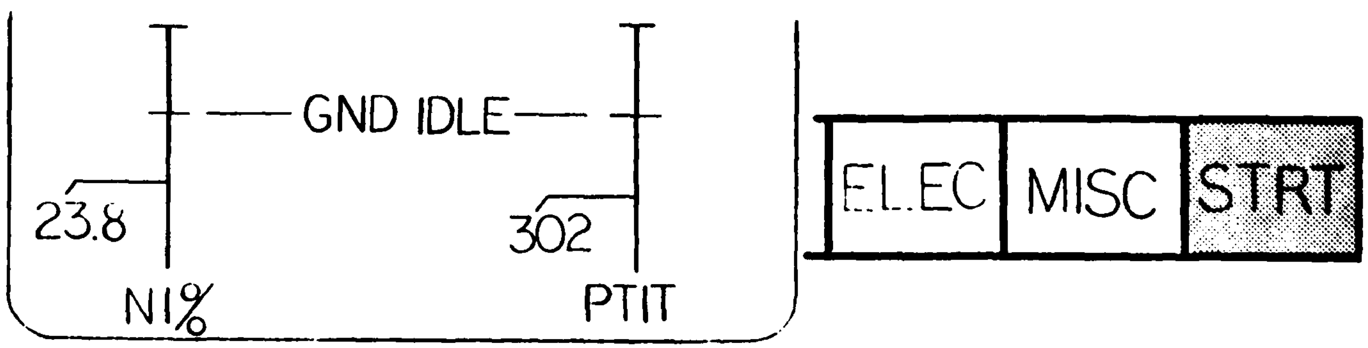
START SW - ON (HOLD, RELEASE)

START FUEL SW. CLOSE

IGN SW.- OFF

"ENG 1 - GND IDLE" takes place of "START ENG 1" when ENG 1 reaches same.

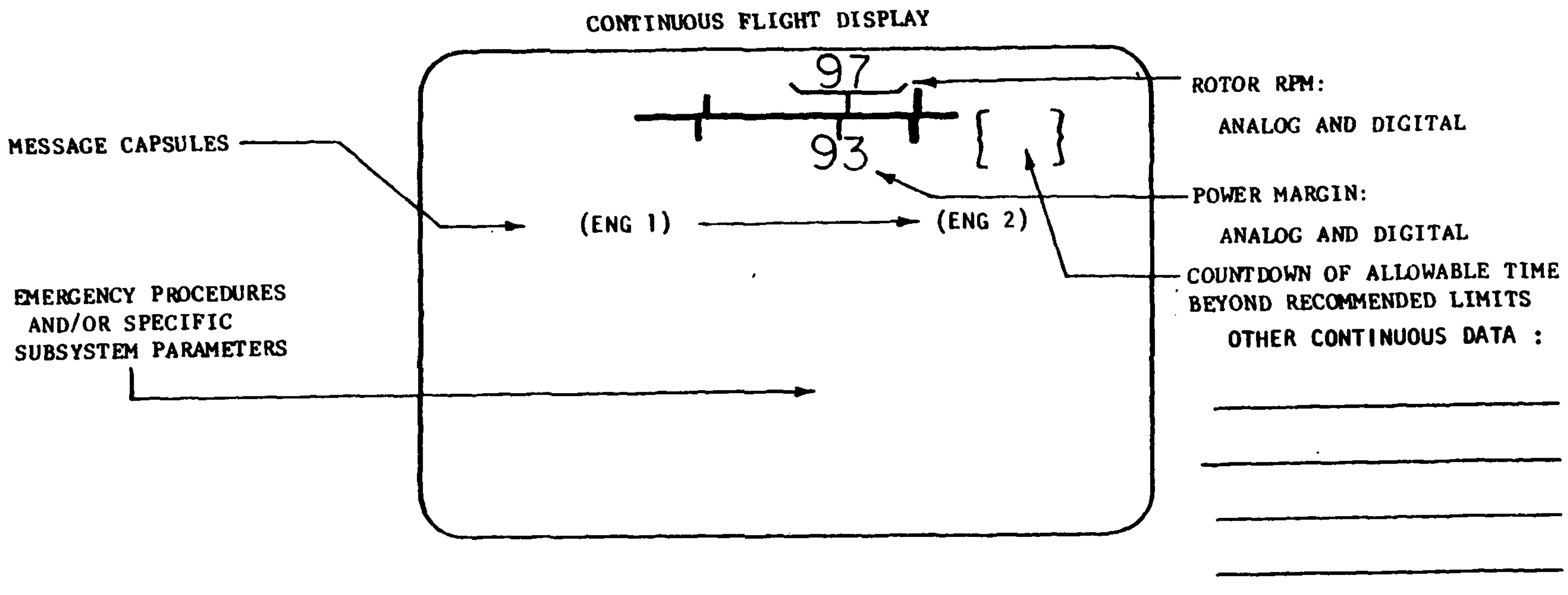
"ON" changes to "HOLD" when start sw is actuated. "HOLD" remains until N1=35/45% "RELEASE" then takes place of "HOLD"



INFORMATION CONTENT FIGURES/

PILOT CRITIQUE SHEET FOR THE

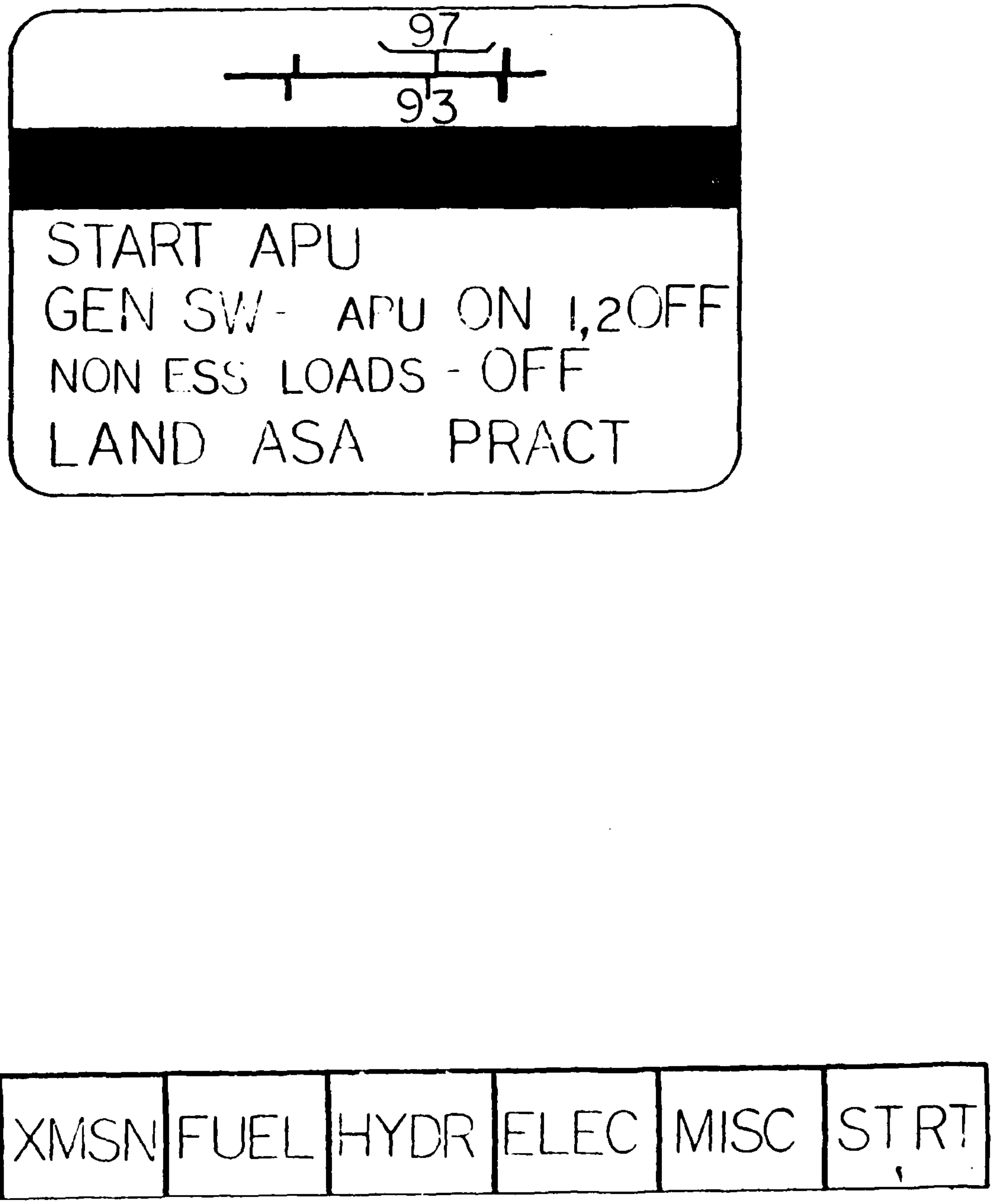
UH-60A




SUBSYSTEM SELECT SWITCHES:

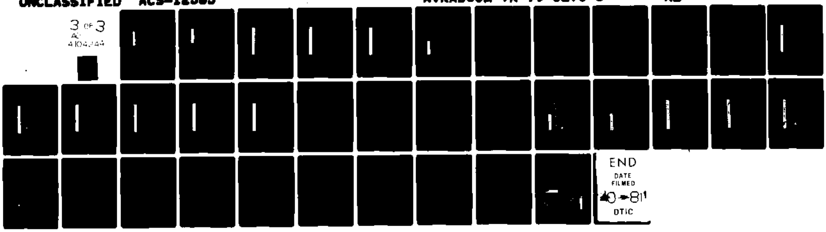
To manually select specific subsystem displays or to acknowledge message capsules.

WARNING MESSAGE DISPLAY
WITH EMERGENCY PROCEDURES



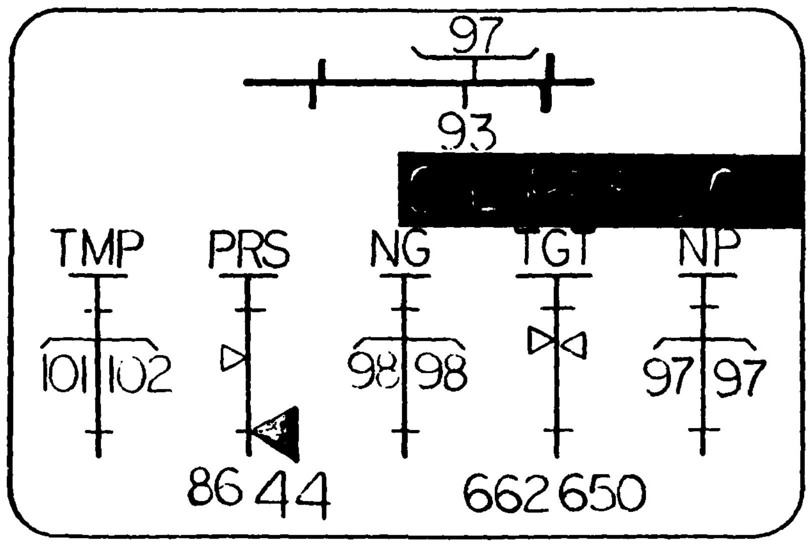
AD-A104 244    GENERAL ELECTRIC CO  BINGHAMTON N Y AIRCRAFT EQUIPMENT DIV    F/G 14/3
ELECTRONIC MASTER MONITOR AND ADVISORY DISPLAY SYSTEM, HUMAN EN--ETC(U)
JUN 81                                                DAAK80-79-C-0270
UNCLASSIFIED    ACS-12385                AVRADCOM-TR-79-0270-3        NL

3 OF 3
AD
A104244



END
DATE
FILMED
10-81
DTIC

:NG1 SUB: EM 'LAY
(WITH WARNING MESSAGE)




OTHER PARAMETERS :

OTHER MESSAGE CAPSULES:

OIL TMP HI

CHIP

ENG STRTR

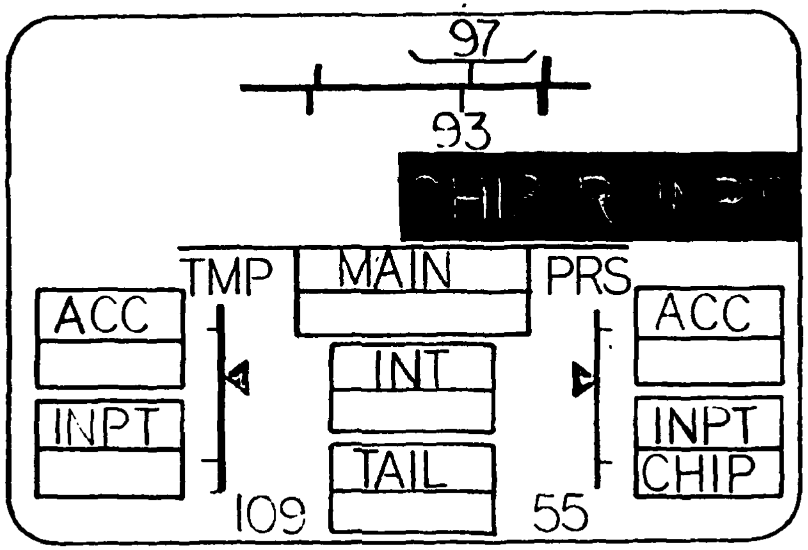
OIL FILTER BYP

ENG OUT

ENG FIRE

| | | | | | | |
|---|---|---|---|---|---|---|
| ENG | XMSN | FUEL | HYDR | ELEC | MISC | STRT |

ISMI ON . YST DISI
(WITH WARNING MESSAGE)




OTHER PARAMETERS :

OTHER MESSAGE CAPSULES:

MAIN XMSN HOT

INT XMSN HOT

TAIL XMSN HOT

(L/R) INPUT - CHIP

INT - CHIP

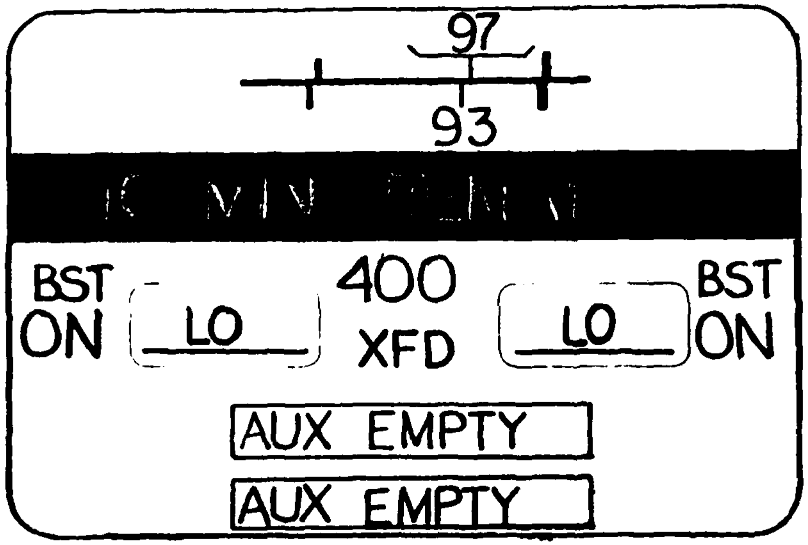
TAIL - CHIP

(L/R) ACCESS - CHIP

MAIN - CHIP

MAIN PRS - LO

FUEL SUBSYSTEM DISPLAY
(WITH WARNING MESSAGE)



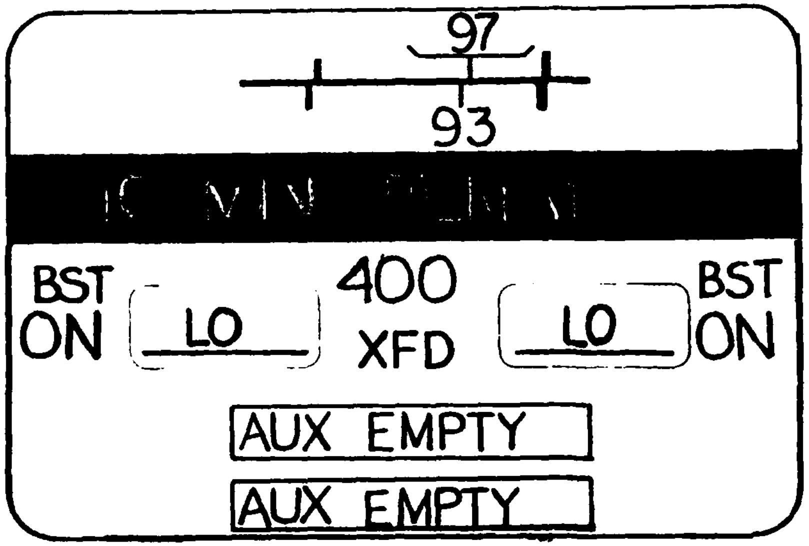

OTHER MESSACE CAPSULES:

FUEL PRS LO

FILTER BYP

OTHER PARAMETERS :

FUEL SUBSYSTEM DISPLAY
(WITH WARNING MESSAGE)




OTHER PARAMETERS :

OTHER MESSAGE CAPSULES:

FUEL PRS LO

FILTER BYP

IYD IC ;YST DIS
(WITH WARNING MESSAGE)

97

93

TAIL FTP SR.C PRS

PRI SRVO PRS ON
BACK UP PUMP OFF
BOOST SRVO PRS ON
HYDR PMP PRS ON

OTHER PARAMETERS :

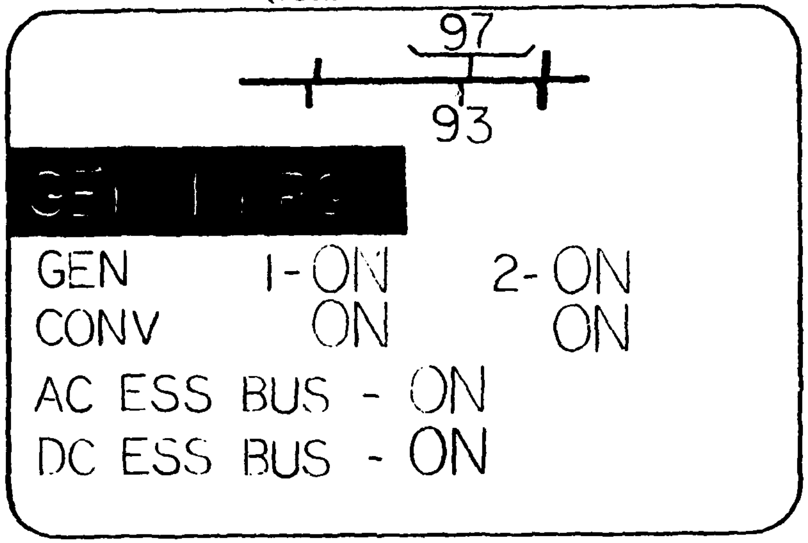
OTHER WARNING CAPSULES

1/2 PRI SRVO PRS
1/2 HYD PMP
BST SRVO OFF
1/2 RSVR LO
BACK UP RSVR LO
APU ACCUM LO

| ENG | XMSN | FUEL | HYDR | ELEC | MISC | STRT |
|---|---|---|---|---|---|---|

~~ TRI~~ SU~~ TEM ~~ PLA~

(WITH WARNING MESSAGE)




OTHER PARAMETERS :

------------------

------------------

------------------

------------------

------------------

------------------

OTHER MESSAGE CAPSULES:

1/2 GEN

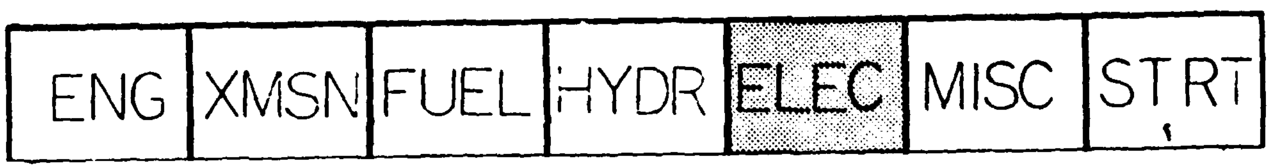
1/2 CONV

BATT LOW CHG

BATT FAULT

APU GEN ON

EXT PWR CONN



**APU START**

FUEL PMP SW - APU BST

APU CONTR SW - ON

EXT PWR SW - OFF

FUEL PMP SW - (AS REQ'D)

BIST - CHECK

MASTER CAUTION - RESET

MISSION EQUIP - CHECK

AVIONICS - ON

COMPASS SW - SLAVED

TAILWHEEL SW - PRESS

GYRO ERECT SW - PRESS

VERT GYRO SW - NORM

CLOCKS - SET

BAROMETRIC ALTIMETERS - SET

RADAR ALTIMETER - ON (HI & LO BUGS SET)

.......,ETC.

ENGINE START/
ROTOR ENGAGEMENT

AIR SOURCE HEAT/START SW - APU, ENG, OFF

CYC, PDL CNTRD, COLL DWN

ENG IGN SW - ON

ENG FUEL SYS SELECTR - XFD

FIRE GUARD - POST

ROTOR BLADES - CHECK CLR

STRTR BTN - PRESS (HOLD 5 SEC)

NG = 52 - 65%

ENG PWR CONT LEVERS - IDLE

ABORT (IF A. NO TGT INDICATION IN 30 SEC.

B. TGT REACHES 810°C BEFORE IDLE

C. NO ENG OIL PRS IN 30 SEC

D. NO NP (1 OR 2) IN 30 SEC)

IDLE NG 65%/63%

ENG PWR CONT LEVERS - FLY

DROOP STOPS - 70-75% RTR

ENG RPM SW - 100%

EXT PWR DISCONNECT

APU CONTR SW - OFF

FUEL PMP SW - OFF

AIR SOURCE HEAT/STRT SW - ENG

ENG FUEL SELECTORS - DIR

EADI - SET

VSI - SET

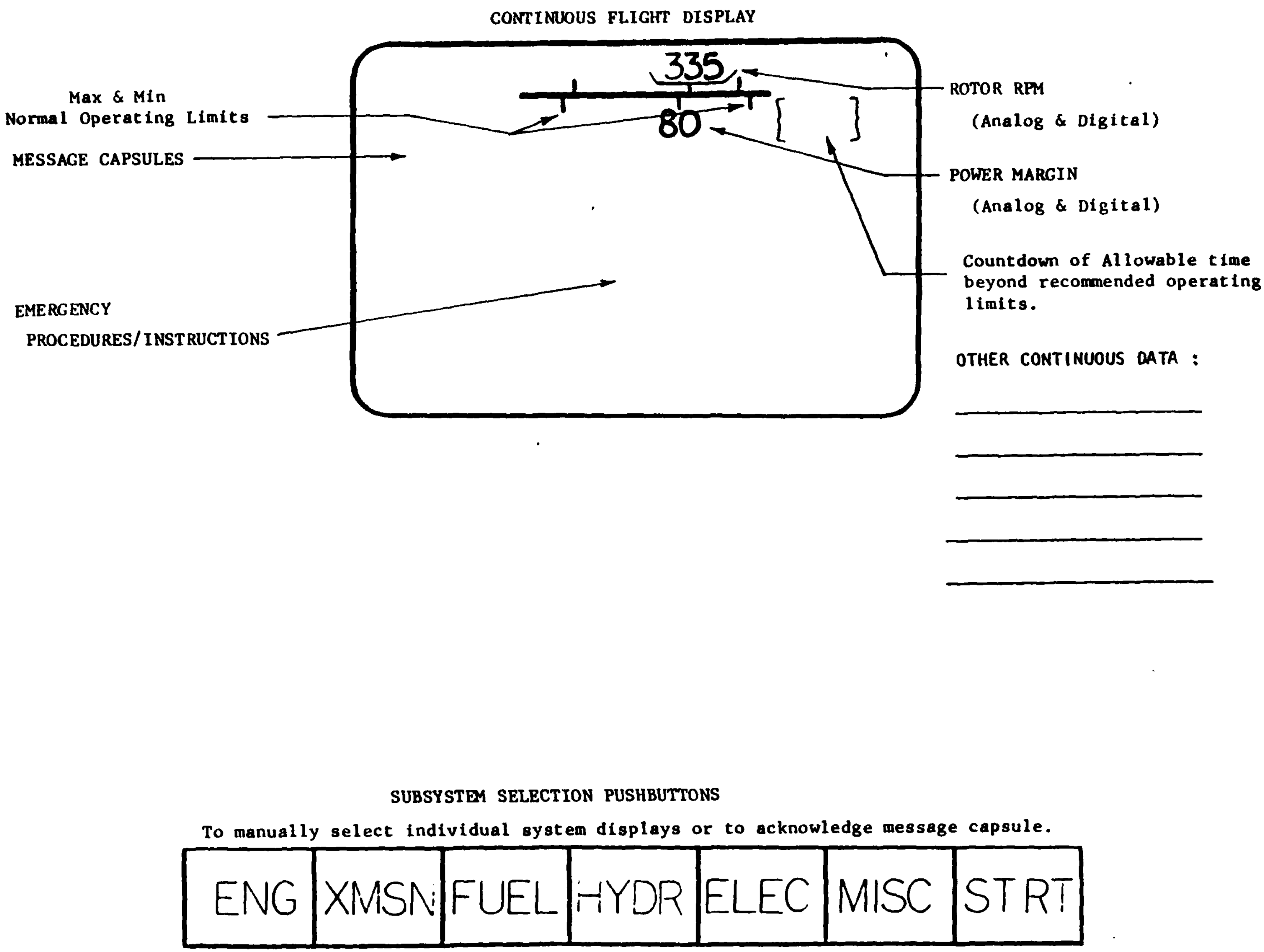
ALT - SET

HIT CHECK - GO/NO GO

INFORMATION CONTENT FIGURES/

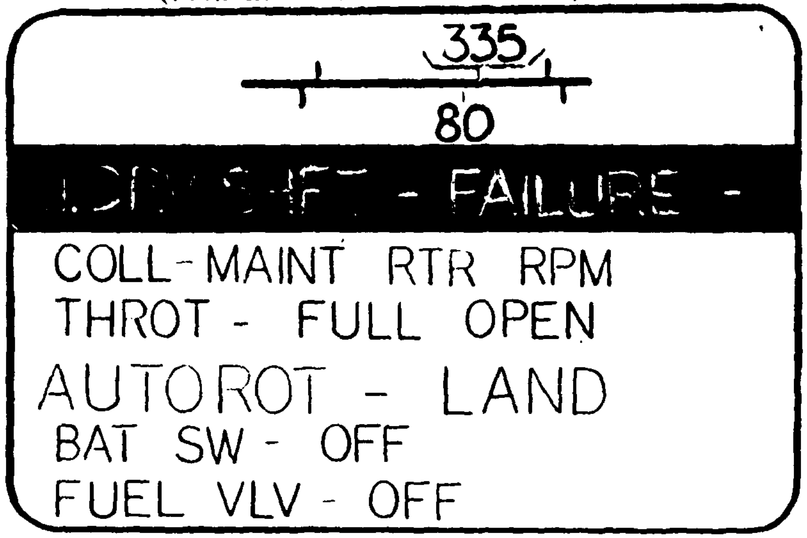
PILOT CRITIQUE SHEET FOR THE

OH-58C


CONTINUOUS FLIGHT DISPLAY
335
80
Max & Min
Normal Operating Limits
MESSAGE CAPSULES
EMERGENCY
PROCEDURES/INSTRUCTIONS
ROTOR RPM
(Analog & Digital)
POWER MARGIN
(Analog & Digital)
Countdown of Allowable time beyond recommended operating limits.
OTHER CONTINUOUS DATA :
SUBSYSTEM SELECTION PUSHBUTTONS
To manually select individual system displays or to acknowledge message capsule.
ENG
XMSN
FUEL
HYDR
ELEC
MISC
STRT

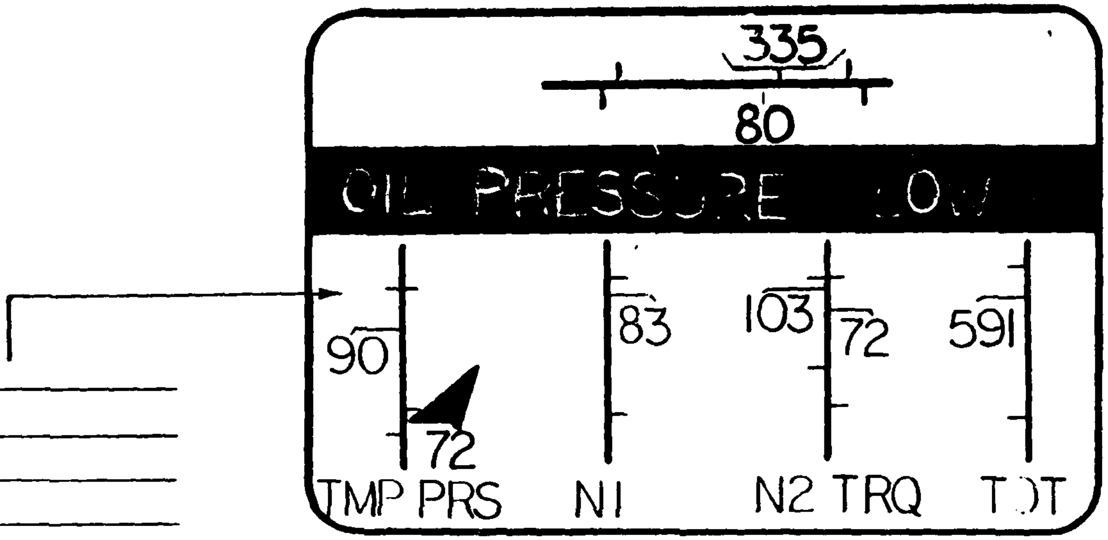
[illegible]LUR[illegible] [illegible]SPI[illegible]

(With Recommended Procedures)




[illegible]NE [illegible]TEM [illegible]PLA

(With Warning Message)




The message capsule has been acknowledged by depression of the ENG pushbutton and this display is presented.

* OTHER MESSAGE CAPSULES:

ENG OIL BYP

ENG OUT

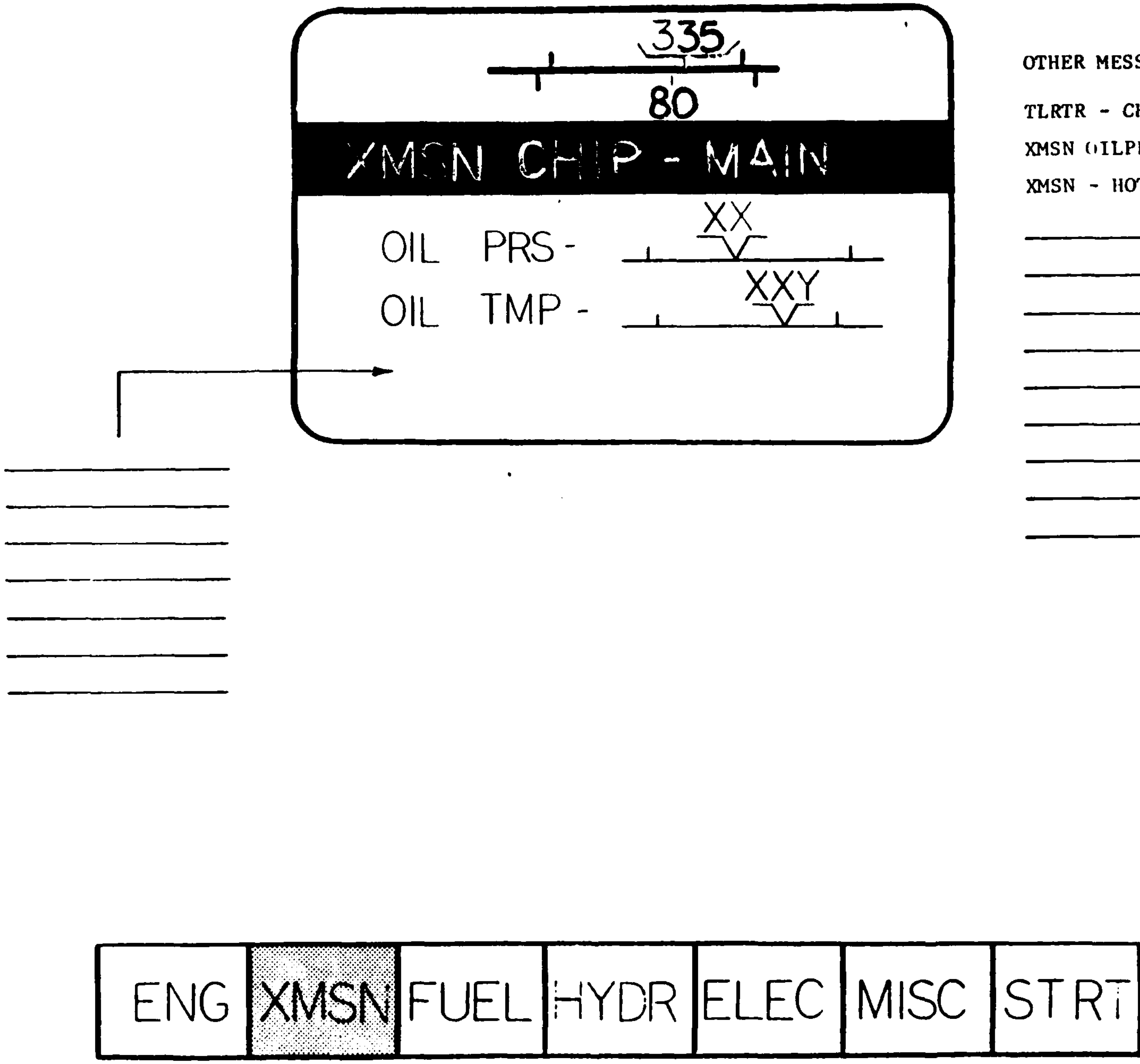
ENG CHIP

OIL TMP - HIGH

OIL PRS - LOW

ENG FIRE

TRANSMISSION DISPLAY
(With Warning Message)



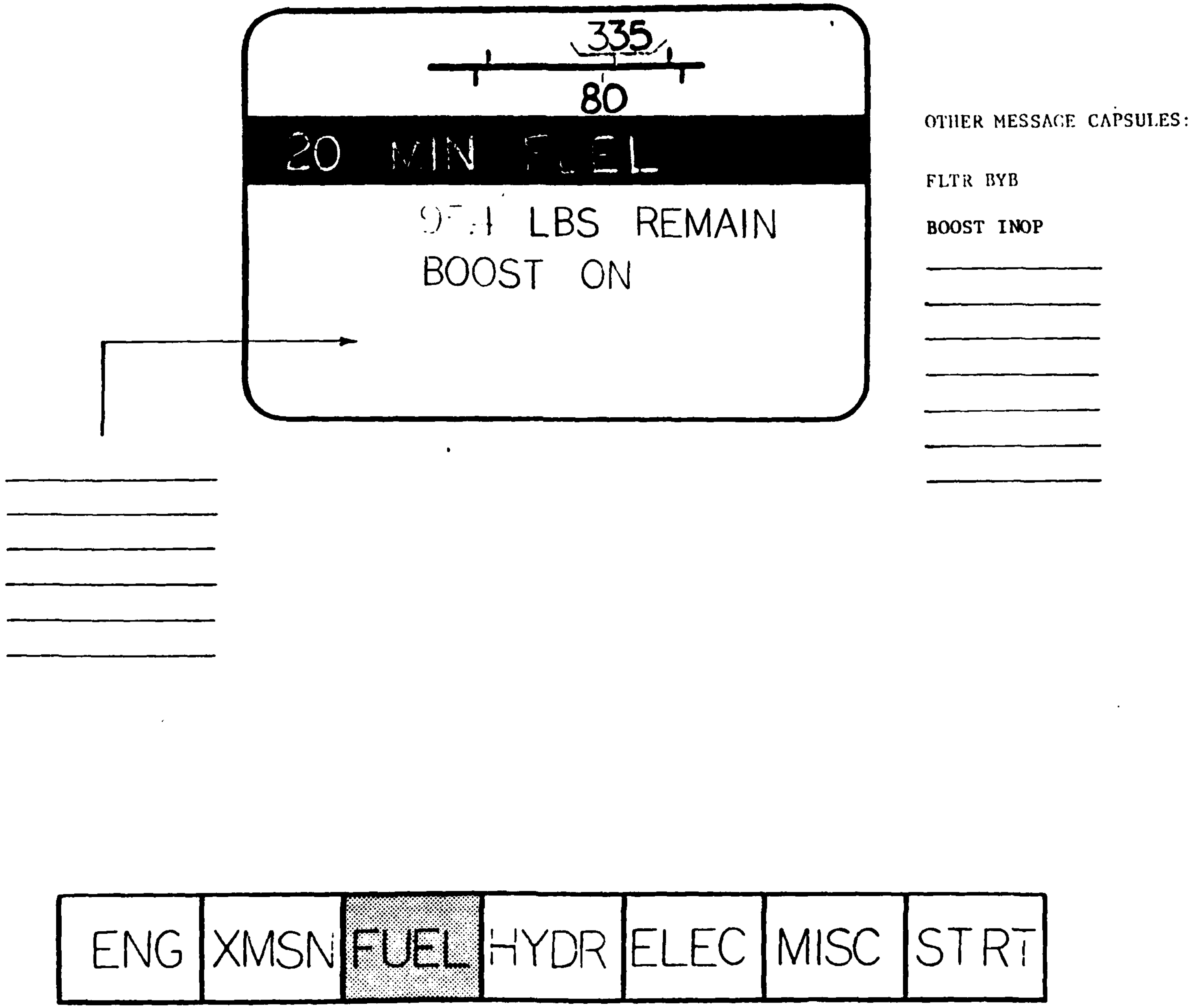

OTHER MESSAGE CAPSULES:

TLRTR - CHIP

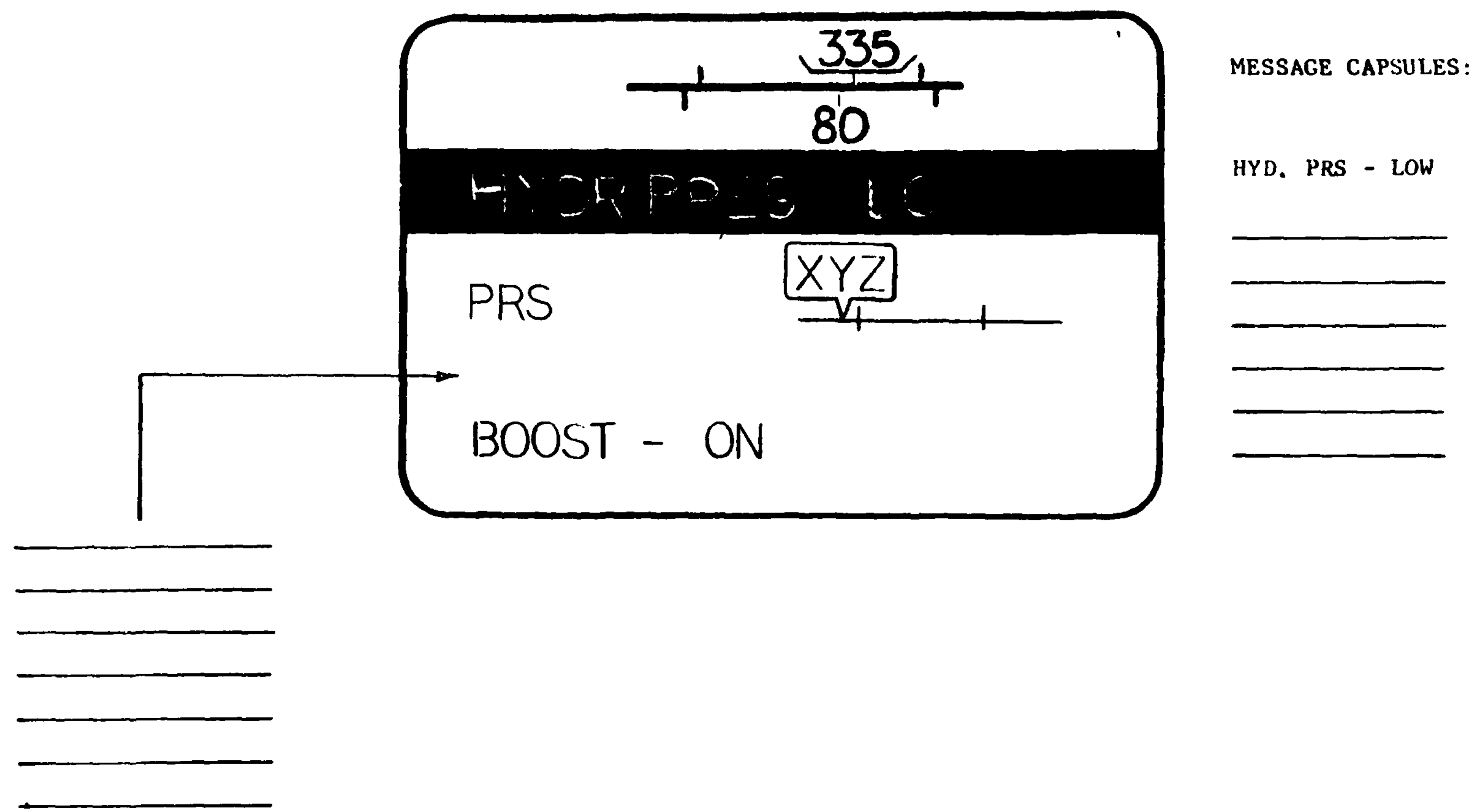
XMSN OILPRS-LOW

XMSN - HOT

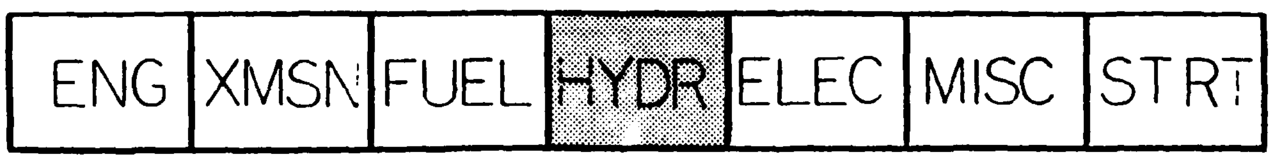
Γ SY ( DI ΛY
(With Warning Message)



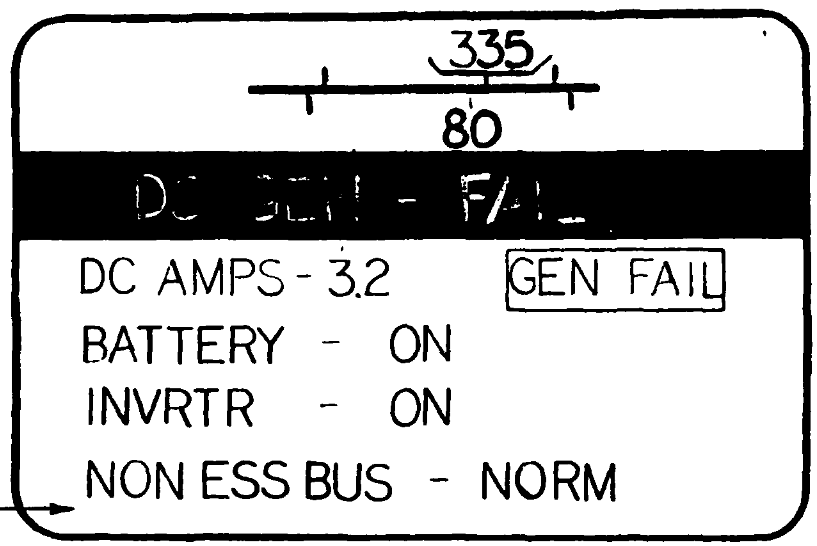
HYDRAULIC SYSTEM DISPLAY




This display appears when the "HYD PRS LO" capsule is acknowledged



ECTF S' M D AY




MESSAGE CAPSULES:

DCGEN-FAIL

INST INV-FAIL

This display appears when the "DC GEN-FAIL" capsule is acknowledged

ENGINE START CHECKLIST

The accomplishment of each item is verified by the system with a ✓ at the right of the display. This is sensed by the position of the specified switch e.g. BAT SW - BAT. Where a pilot/copilot visual task is required e.g. "CLEAR ENG AREA" the "STRT" select button is pushed to enter a check and advance the ➡ to the next item. At the end of the page the ✓ item is retained as the top item on the display with the remaining items below.

After start button is depressed a digital/analog display of N1, N2 & T.O.T. become a permanent part of the lower portion of the display. Checklist items continue to be cycled through the top portion of the display.

ENG START

BAT SW - BAT ✓

➡ GOV RPM SW - DECR (HOLD, RELEASE)

THROTTLE - CK CLOSED

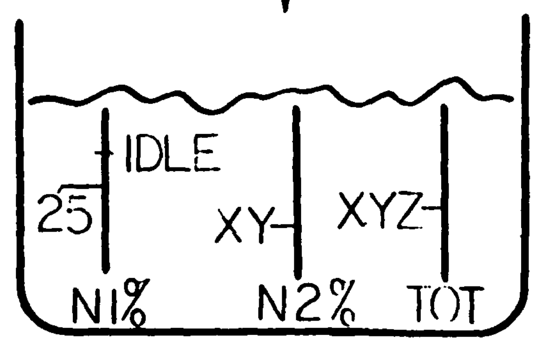
STRT - IGN SW - ON

ROTOR BLADES - CHECK

POST FIREGUARD

START BUTTON- PRESS* (HOLD, RELEASE)

* "HOLD" appears after button is depressed.
"RELEASE" appears after N1 reaches 62%.




THROTTLE TO IDLE

(N1 = 15% + FOR 7° - 54°C)

OBSERVE ROTOR MOVING

(IF NO MOVEMENT BY N1 = 30% - ABORT STRT)

CK ENG IDLE - (N1 = 62 -63%)

(IF N1 < 58% IN 45 (60) SEC
CLOSE THROTTLE, MOTOR ENGINE FOR
10 SEC UNTIL TOT < 200°C)

THROTTLE INCR SLOW TO FULL OPEN

OBSERVE N2 = 97% +

GOV RPM SW - INCR TO 104% NG

- RESET TO 103% N2

CHECK: FUEL QTY

CHECK: N2 = 103%

FUEL BOOST PUMP - OFF

HIT:

DC AMPS STABILIZED 60

TURN OFF ALL BLEED AIR

READ OAT INTO WIND

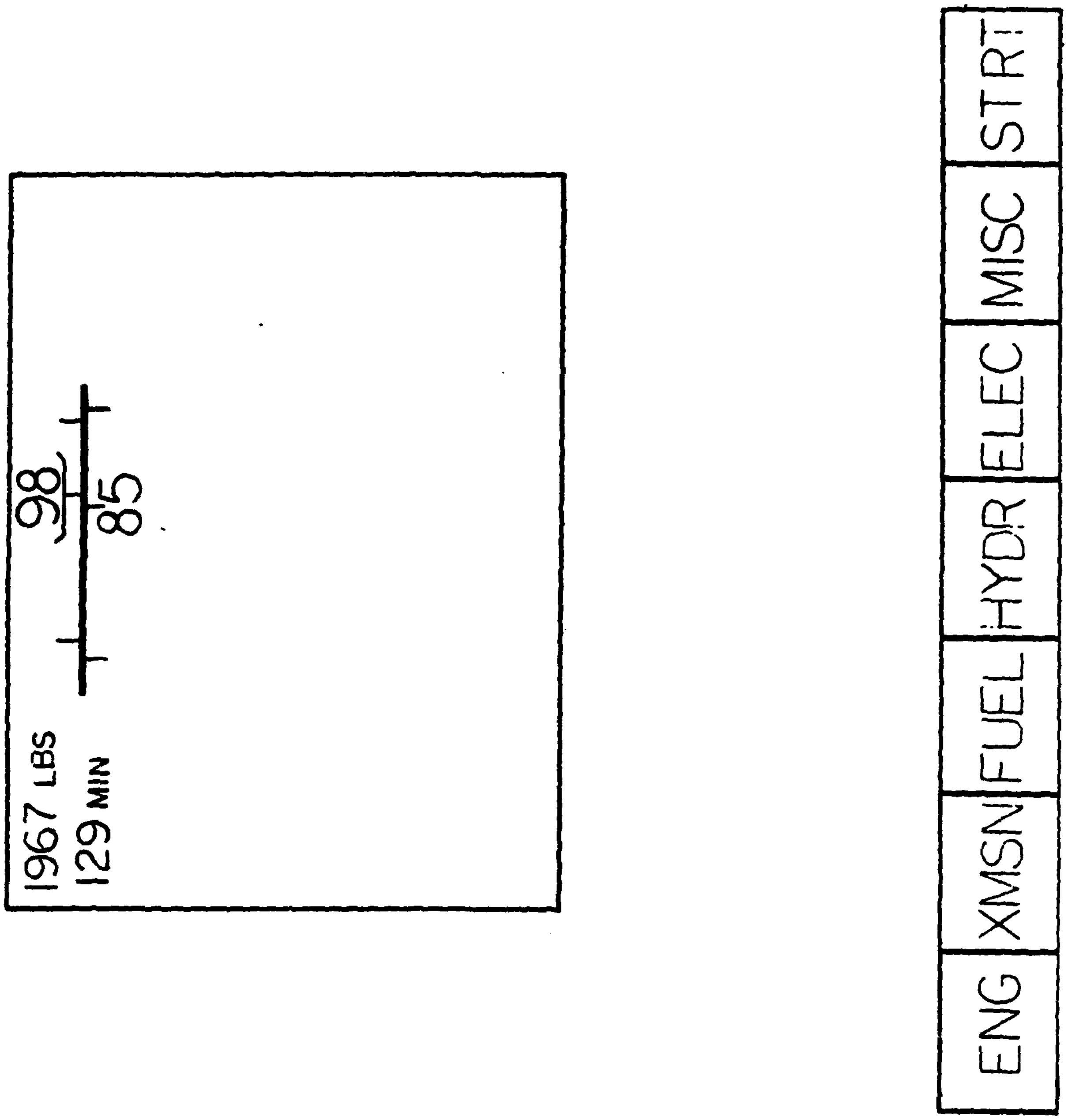
SET N1 AT "TBD"

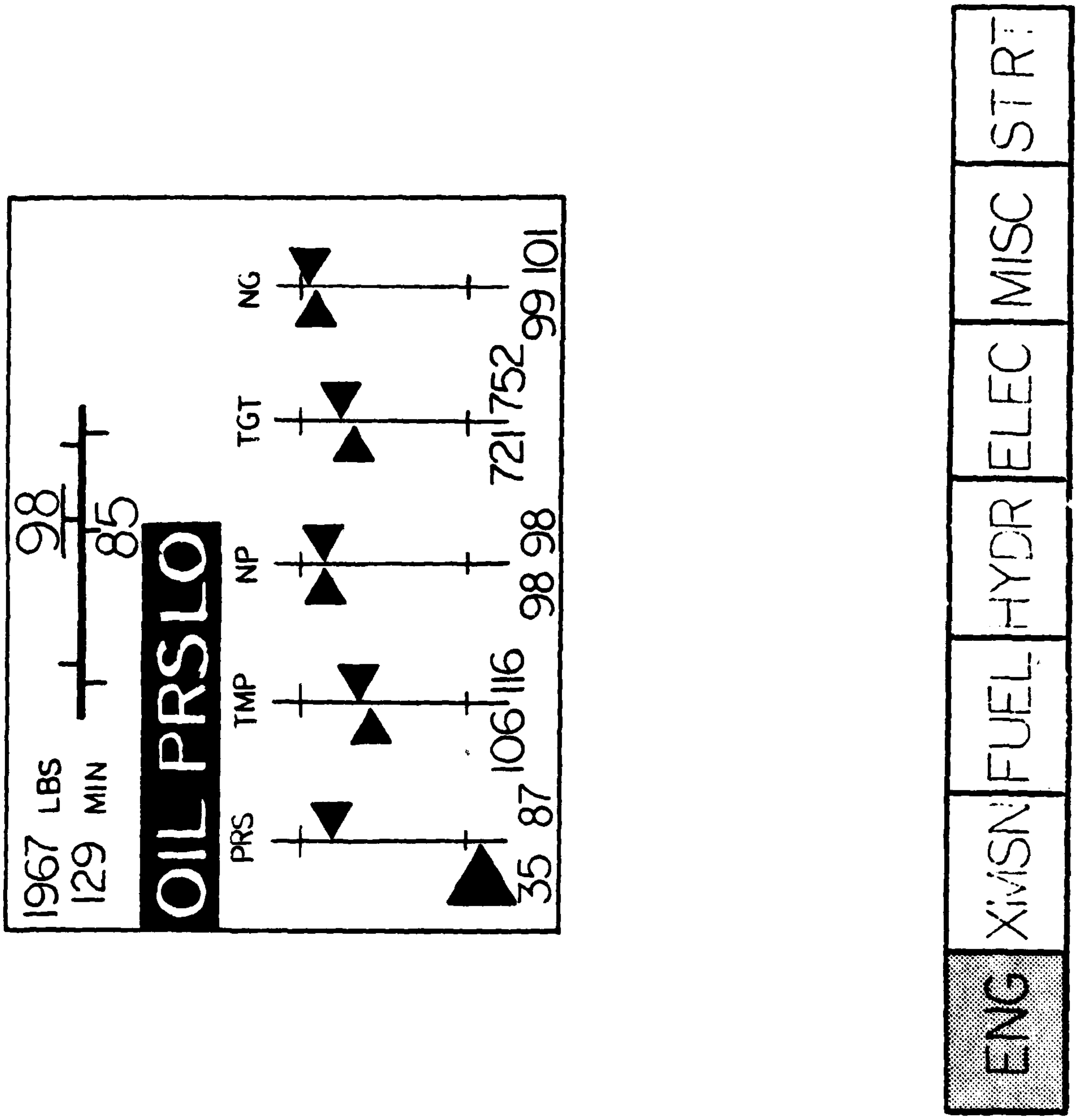
OBSERVE HIT RESULT (OK, DO NOT FLY, ETC.)

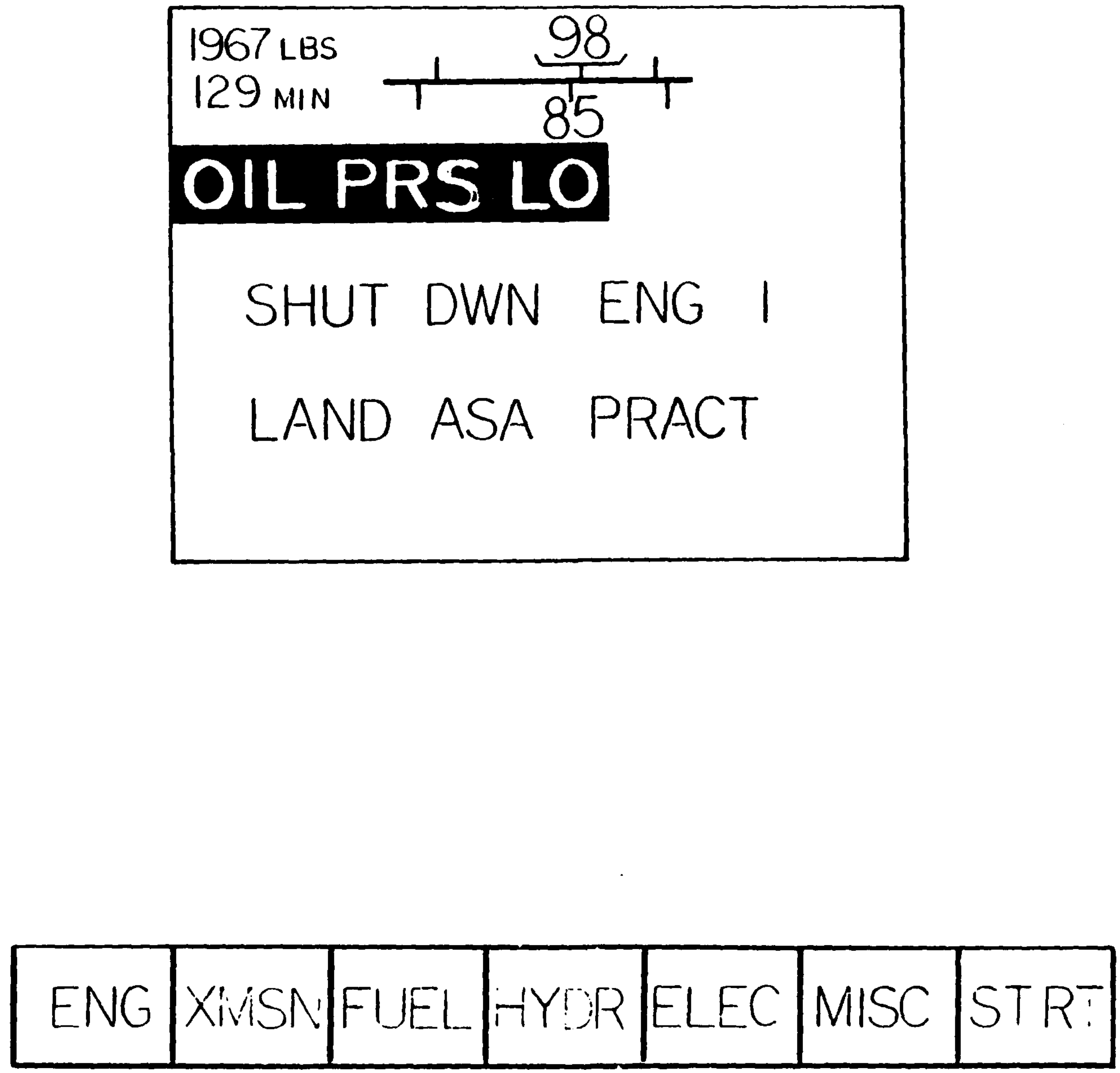
INFORMATION CONTENT FIGURES/

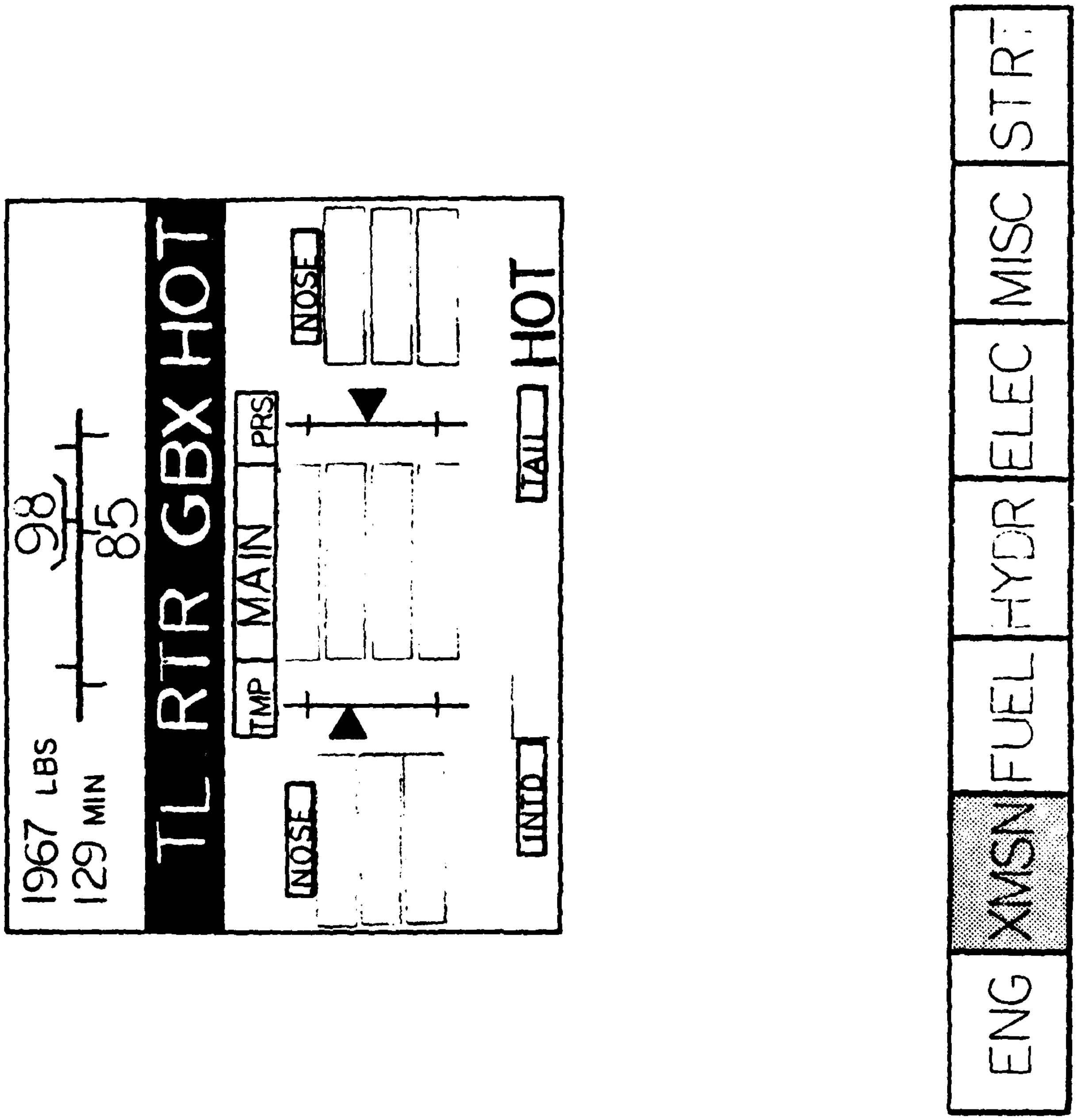
PILOT CRITIQUE SHEET FOR THE

YAH-64

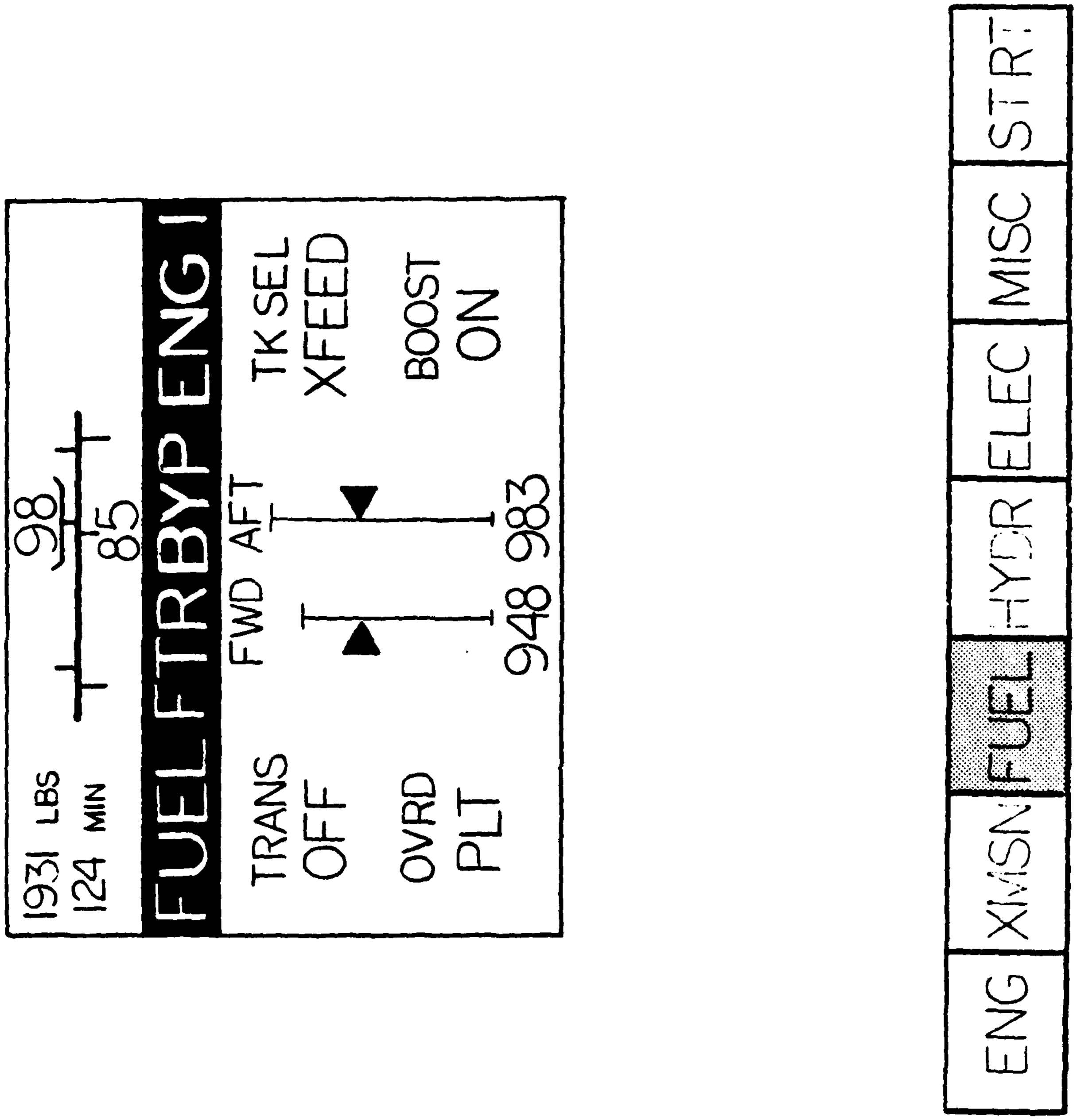

1967 LBS
129 MIN
98
85
ENG
XMSN
FUEL
HYDR
ELEC
MISC
STRT

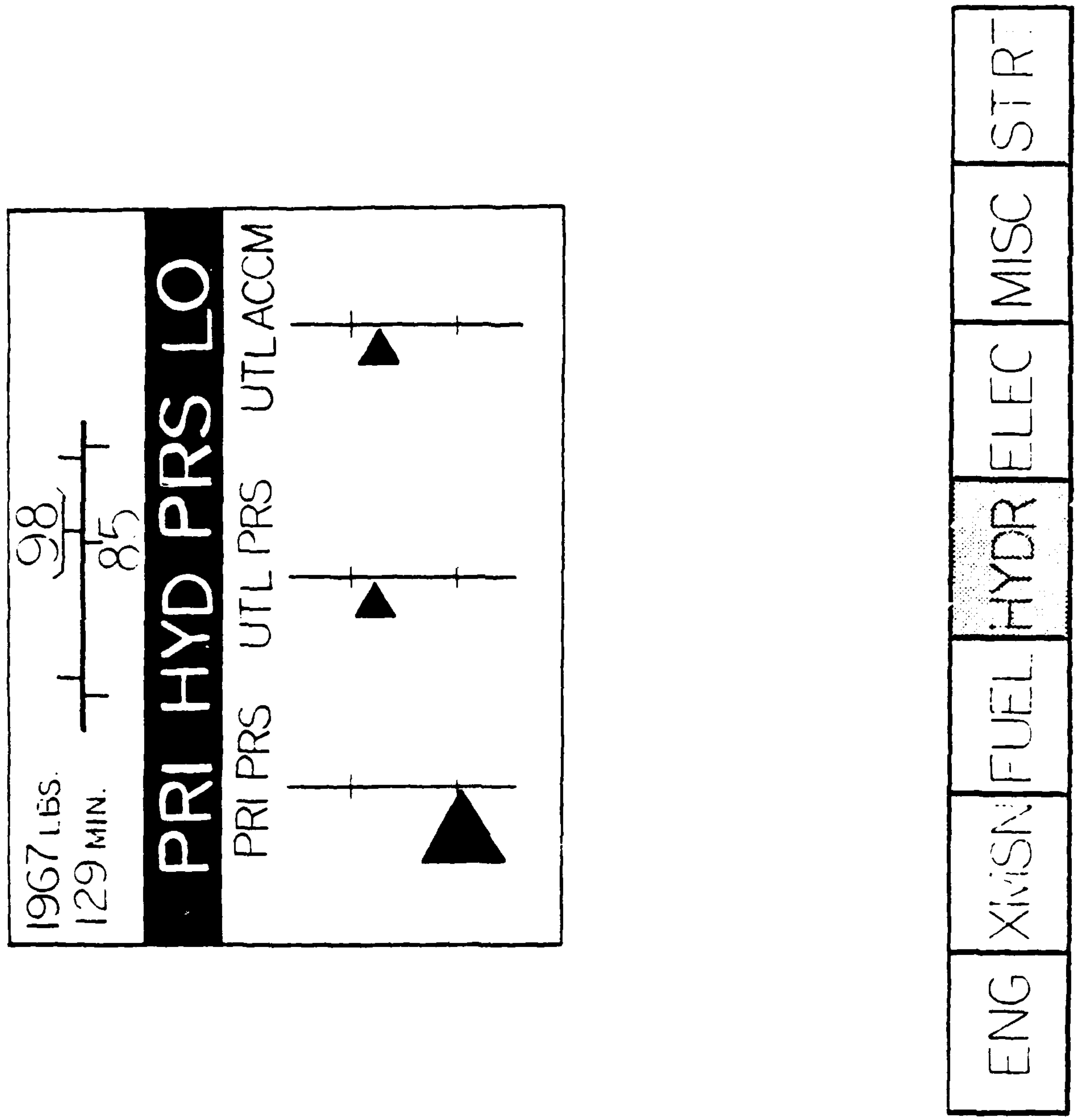

1967 LBS
129 MIN
98
85
OIL PRS LO
PRS
TMP
NP
TGT
NG
35
87
106
116
98
98
721
752
99
101
ENG
XMSN
FUEL
HYDR
ELEC
MISC
STRT


1967 LBS
129 MIN
98
85
OIL PRS LO
SHUT DWN ENG I
LAND ASA PRACT
ENG
XMSN
FUEL
HYDR
ELEC
MISC
STRT



1967 LBS
129 MIN
98
85
TL RTR GBX HOT
TMP
MAIN
PRS
NOSE
NOSE
INTD
TAIL
HOT
ENG
XMSN
FUEL
HYDR
ELEC
MISC
STRT


1931 LBS
124 MIN
98
85
FUEL FTRBYP ENG
TRANS
OFF
OVRD
PLT
FWD AFT
948 983
TK SEL
XFEED
BOOST
ON
ENG
XMSN
FUEL
HYDR
ELEC
MISC
STRT


1967 LBS.
129 MIN.
98
85
PRI HYD PRS LO
PRI PRS
UTL PRS
UTL ACCM
ENG
XMSN
FUEL
HYDR
ELEC
MISC
STRT

START ENG X

| | | |
|---|---|---|
| AREA CLEAR | | |
| POST FIRE GUARD | | |
| ENG FUEL SW | - | ON |
| ROTOR BRAKE SET | | |
| ENG X START SW | - | START/RELEASE |
| ENG X POWER LEVER | - | IDLE |
| ENG INLET ANTI-ICE SW | - | AS REQ'D. |
| ROTOR BRAKE SW | - | OFF |
| ENG X POWER LEVER | - | FLY |

| | | | | | | |
|---|---|---|---|---|---|---|
| ENG | XMSN | FUEL | HYDR | ELEC | MISC | STRT |

# APPENDIX D

## EMMADS SYSTEM DESCRIPTION FOR FT. CAMPBELL FLIGHT CREW INTRODUCTION

EMMADS

An Electronic Master Monitor and Advisory Display System (EMMADS) is presently being developed. The purpose of this system is to unburden the crew by monitoring and evaluating the status of certain aircraft subsystems. The basic concept is to display (on a flat panel device) only the data necessary for the situation. While certain performance parameters (rotor RPM and power margin) will be displayed at all times, other subsystem data/status will be displayed automatically if a fault or marginal condition occurs or if manually requested by the crew. Measurable data from the following subsystems will be incorporated into the EMMADS:

ENGINE

TRANSMISSION

ROTOR

FUEL

HYDRAULIC

ELECTRICAL

STABILITY AUG.

MISC - Incl. Cargo hook, Pitot-Heat, Parking Brake, L. Gear etc.

A large percentage of the information describing the temp, pres., RPM, etc. of these subsystems will not be routinely displayed unless some fault/irregularity is detected by the monitoring system.

If a marginal or critical condition is sensed e.g. high engine oil temp, a message capusle (similar to that currently presented on the caution warning panel) would appear on the EMMADS display "ENG 1 OIL TEMP HIGH."

The master caution light would also be illuminated. If appropriate, the recommended procedure to handle this condition would also be displayed "LAND AS SOON AS PRACTICABLE-BE PREP. TO SHUT DOWN ENG 1."
The crew member would acknowledge this message by depressing the brightened and/or flashing subsystem button - "ENGINE" or by depressing the master caution switch.

This would bring up on the display a complete engine subsystem display. This display would contain the status of all engine parameters in either digital (numeric readout) and/or analog (scale and pointer, bar chart, etc.) form. Discrete indications such as N1 CONT would also appear, if appropriate.

Although most of the subsystem information will not be displayed unless a) a fault or marginal condition occurs or b) data is manually requested, certain flight related parameters will be displayed continuously. These indications which will be displayed at all times will include:

a: Rotor RPM

b: A composite indication of power margin

or c: Individual indications of N1, Torque and EGT.

In summary, EMMADS will serve as a subsystem data manager. The system will perform the routine status checks normally done by the crew. This allows pilot and copilot to devote <u>all</u> of their time and visual attention to flight and mission related activities. In the event of a malfunction or marginal condition, the system will a) assess the status of all the related parameters b) determine what the malfunction/condition is and c) report to the crew what the problem is and what the recommended course of action should be. Thus EMMADS removes the burden of the crew having to interpret many parameters of raw data in determining the exact source of a malfunction.

As an example, if EMMADS diagnoses a (high side) engine beep trim failure and provides appropriate corrective action procedures, the crew can immediately and correctly respond to the malfunction. Conventional instruments would indicate symptoms indicative of a beep failure or an N2 overspeed drive shaft failure. Since the corrective actions are different the crew might have to perform both procedures to correct the problem. This feature greatly reduces the possibility of misinterpretation of symptoms (and consequent inappropriate reaction) and minimizes the time away from vital flight and mission tasks.

Since the performance parameters (Rotor RPM and Power Margin) are continuously displayed and the individual subsystem parameters (temps, pressures, RPMs, status, etc.) are displayed automatically, with warning message or upon request by the crew, no information has been taken away from the crew. It is merely presented only when needed (or requested).

It is the intent of EMMADS to perform the tasks of routine status monitoring and criticality/malfunction analysis thus reducing the crew's (subsystem) work-load and providing more time for critical mission activities such as during NOE flight.

Display and control hardware for EMMADS will include a flat panel display(s) and an array of subsystem select actuators. The following pages show the results of the preliminary designs for the information which will appear for each sub-system and for each category; continuous, by manual request, and by exception (when fault or warning occurs). It should be noted that the format and layouts shown here are not necessarily those being recommended for the system. The intent of the following figures is to define the information CONTENT for each display situation-NOT THE INFORMATION FORMAT.

INSTRUCTIONS

Based on the above description of EMMADS and other discussion (question and answer session, etc.) please do the following:

Consider, for any (and all) operational situation(s) that, in place of your present subsystem instruments, you have an EMMADS. Evaluate and critique each of these displays for their ability to provide you with the information you need for that particular situation.

1. In the space available, indicate additional information (message capsules, raw data or discrete indicators) which you feel is necessary and should be included in that display.
2. Indicate those parameters/indications that should be eliminated from each display if they are useless or superfluous.
3. In general, provide any comments you may have which are pertinent to the content of these displays. Specifically, the following three areas of information might be considered.

A. COMPOSITE INDICATIONS

Could the usefulness of the display be improved if some parameters were combined to yield a composite indication, thereby eliminating mental arithmetic, etc? For example, by combining fuel consumption rate (LBS/HR), air speed (knots), and fuel remaining (lbs.) EMMADS could compute time and/or range remaining. This could become part of the continuously displayed information.

B. TREND INFORMATION

Would it be advantageous to be informed by EMMADS that a parameter like trans. oil temp was slowly increasing, although it has not yet reached a critical value. Please consider the usefulness of this type indication and indicate those parameters where it might be appropriate by writing the word "TREND" next to the parameter.

C. OPERATIONAL/ENVIRONMENTAL CONDITIONS

Consider the adverse situations imposed by both operational requirements (NOE, night, etc.) and environmental conditions (Artic/Jungle climate, high altitude, IMC). Do these, or other situations impose unique requirements which would effect the content of the specific EMMADS displays shown here and should different displays be designed to handle these situations?

For the purpose of this description, the following terms have been used in describing the operational characteristics of the example displays.

| | |
|---|---|
| ANALOG | - A spatial representation of a parameter's value along a continuous path or direction. Examples include moving bar charts, fixed scales with moving pointers, conventional dial and needles. |
| DIGITAL | - Numeric readout |
| DISCRETE | - Word(s) or symbol indicating a state (ON/OFF) or condition (TEMP HIGH). |

APPENDIX E

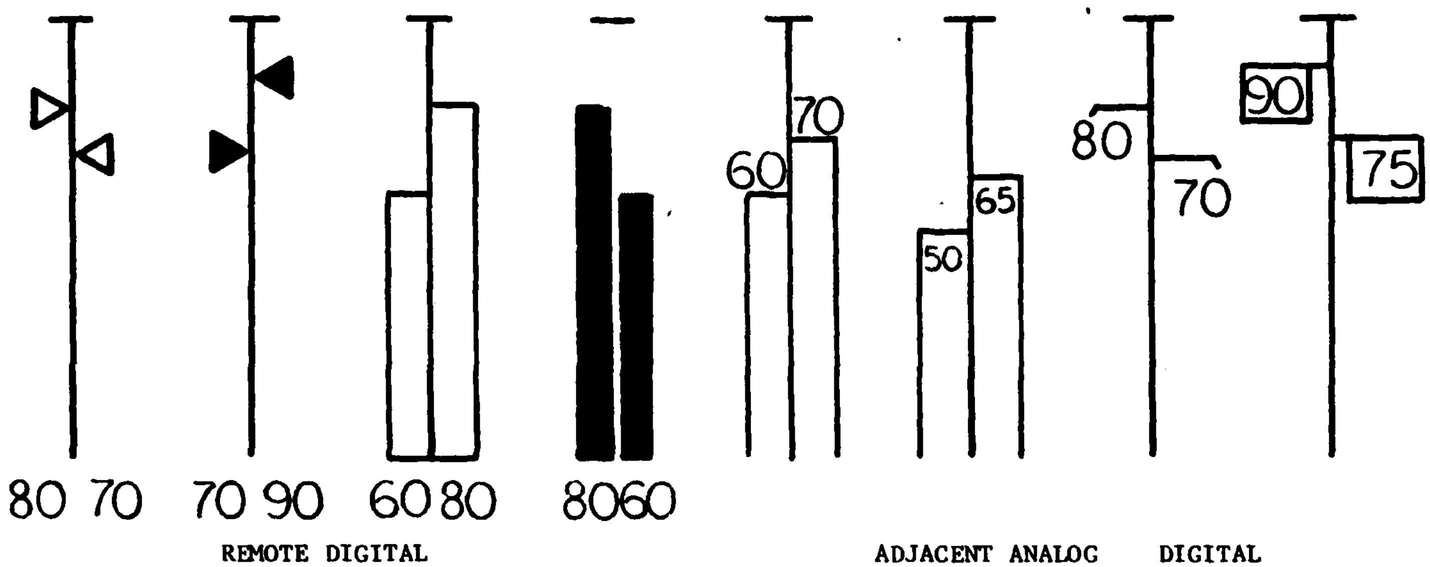
BASIC HFE TEST PROGRAM - INSTRUCTIONS FOR SUBJECTS

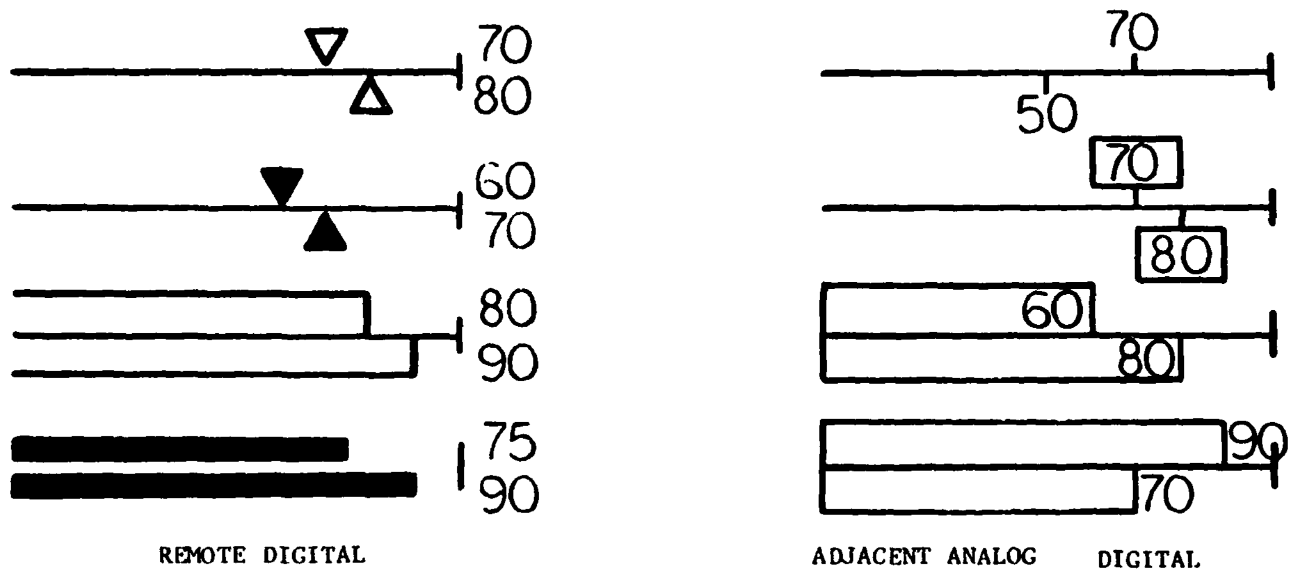
## INSTRUCTIONS

This testing is designed to measure the ability of certain display formats to provide an operator (pilot) with quantitative and qualitative information. To assess this attribute of the display formats, you will be asked a question about the data which is to be displayed and the display will then be flashed on the screen for a short time interval. If you are unable to answer the question, the display will be repeated until an answer is given. Your performance (and consequently the ability of the display to provide information) will be measured by the number of repetitions of the display required to answer the question.

The displays will be of two general types - Horizontal and Vertical. Each type will present the values of four variables A, B, C, and D. The values will be presented in both analog and digital form. The techniques shown on the next page will be used to portray the analog form. The digital values will be either remote or adjacent to the analog indication as shown on the next page.

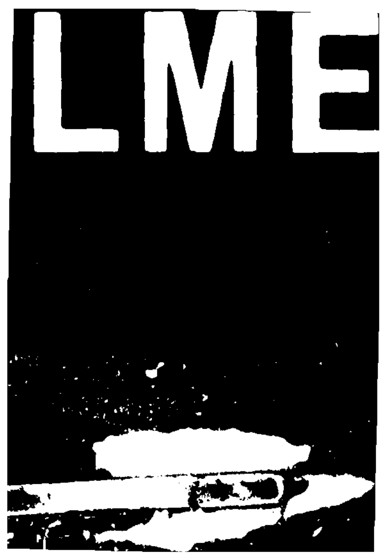
VERTICAL FORMATS




☆ U.S. GOVERNMENT PRINTING OFFICE: 1981 – 703-073/FM-C-53-81

HORIZONTAL FORMATS


LME